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# ICEBREAKER MIDBODY RESISTANCE

## - PHASE II; BEAM VARIATION -

## TP 10161E

For

**Transportation Development Centre**
Policy and Coordination Group
Transport Canada

By

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## PROJECT TEAM

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## LANGUAGE NOTICE

Un sommaire en français de ce rapport est inclus avant la Table des matières.

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16. Abstract

A series of 1:30 scale model tests have been conducted on the ice capable cargo ship M.V. ARCTIC.

The previous tests have included an analysis of friction coefficient and midbody length. The tests described in this report relate to the analysis of the influence of beam on model resistance. Three model beams are tested, the original beam, a beam 20% wider and 20% narrower. In addition to the beam variation series, a number of the models were also run with different midbody lengths to integrate this program with previous work.

The results of the work present uniform relationships between model resistance, beam, and length and indicate a low sensitivity of length/breadth ratio.

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16. Résumé


Des essais sur la maquette 1:30 du cargo brise-glace N.M. Arctic ont eu lieu dans un bassin de glaces.

Les essais antérieurs avaient approfondi l'influence de la longueur de la section rectangulaire médiane de la coque et celle du coefficient de frottement. La recherche dont il est rendu compte ici concerne l'influence de la largeur du bau sur la résistance à l'avancement. Trois maquettes de l'Arctic ont été construites, l'une représentant le navire dans sa forme actuelle et les deux autres avec une coque dont le bau est de 20 p. 100 plus grand et de 20 p. 100 plus petit. Les essais ont porté également sur des maquettes dont on pouvait faire varier la longueur par l'addition ou l'enlèvement de segments à la section médiane de la coque; il s'agissait de pouvoir intégrer, ce faisant, les résultats de la présente étude aux résultats obtenus antérieurement.

La recherche a montré le rapport uniforme qui existe entre résistance à l'avancement, bau et longueur et met en évidence la faible influence du rapport longueur/bau.


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## SUMMARY

Model tests were conducted at the Institute for Marine Dynamics (IMD) in St. John's, Newfoundland on a 1:30 scale model of the MV ARCTIC, an Equivalent Arctic Class 4 O.B.O. carrier. Models were constructed to represent the existing ARCTIC and two parametric beam variations of the same hull form, 20 percent wider and 20 percent narrower. The test program also included a length variation analysis by removing and adding midbody segments to each model. The model tests consisted of 8 towed resistance tests in model EG/AD/S ice representative of winter first year ice, 0.9 m and 1.2 m thick and with a flexural strength of 500 kPa. These ice thicknesses and strength correspond to 30 mm and 40 mm and 16.67 kPa model ice.

The Ship Resistance vs Beam, Length and L/B ratio relationships for each model demonstrated a consistent trend for the series of models tested. The results also correlated well with the previous MIDBODY and FRICTION test programs. This will permit an improved understanding of how ice performance may be optimised to achieve the best combination of ship length and breadth.

An examination of the component parts of the total resistance, as defined by the breaking and clearing components, did not result in any consistent trends that would indicate which component was most influenced by the change of length and/or bow form. It was concluded that this result questions the basis upon which clearing and breaking components of resistance are used in the non-dimensional analysis.

In addition to the ARCTIC model a second ship, the NORDIC, which has a similar bow and an intermediate L/B ratio, was also compared to the data set. Unfortunately, the correlation between these two vessels was not close; this is believe to be due to the midbody flare and waterline knuckle on the NORDIC bow which are not present on the ARCTIC bow.

The recommendations from this report may be summarized as follows:

a) The analysis procedure adopted in this report was developed by Dr. B. Colbourne of the IMD and is currently extensively used in that facility. This method follows a different analysis procedure than adopted with the MIDBODY and FRICTION test programs. Based on the analysis conducted in this report, it is believed that different analysis procedures may result in significantly different results. It is therefore strongly recommended that a standard analysis procedure be developed based on an analysis of all model tests performed at the IMD.

b) The definition of model ice mechanical properties must be improved through a standard procedure that may be used for all model tests. This work is currently in the final stages of development with the INDEXER, a device invented by Melville Shipping and developed with the assistance of IMD and the Transportation Development Centre. The INDEXER should be adopted as a standard measuring device for all model tests in ice.

c) The continuing development of relationships between hull form and resistance should be pursued with a focus on the breaking component of resistance and the subsequent scaling relationships between model and full scale data. One major influence on scale relationships and the breaking component is considered to be the size and orientation of the ice cusping occurring at model scale. It is recommended that the influence on cusp size of model speed, ice strength and thickness be measured and compared with full scale data that could be obtained from the ARCTIC. This will permit more accurate definition of model/full scale scaling relationships.

d) The MIDBODY program is the third in a series of model tests which have provided a consistent set of data for the ship designer. The next logical step in this process is considered to be an investigation of the influence of longitudinal radius of gyration on the model resistance. The MIDBODY and BEAM variation tests have permitted an understanding of two of the "size" variables with respect to performance, beam and length. The third important variable is considered to be the influence of the displacement of the model. This is manifest in the response of the model to the icebreaking process, which is controlled by the longitudinal radii of gyration. It is proposed that a series of tests be conducted with the ARCTIC and one other model to investigate the influence of this variable on resistance. The model would first be tested fully constrained and then with decreasing levels of longitudinal radii of gyration. The results could be used in conjunction with the existing data base of model test information on the ARCTIC to evaluate the influence of model size on resistance.

## SOMMAIRE

Des essais ont eu lieu dans le bassin des glaces de l'Institut de dynamique marine 9IMD0 à St. John's (Terre-Neuve), sur la maquette 1:30 du N.M. Arctic, vraquier de cote arctique 4. Les maquettes construites représentaient respectivement la forme actuelle de l'Arctic et deux variantes paramétriques, l'une avec un bau de 20 p. 100 plus grand et l'autre avec un bau de 20 p. 100 plus petit. Ces essais ont porté également sur des maquettes de longueur variable, par l'addition ou l'enlèvement de segments à la section rectangulaire médiane de la coque. Chaque maquette a fait l'objet de huit essais de résistance à l'avancement dans une glace modèle EG/AD/S d'épaisseur et de résistance correspondant à des glaces réelles de 0,9 et de 1,2 m d'épaisseur et de 500 kPa de résistance en flexion. Les paramètres correspondants de la glace-modèle ont été de 30 et 40 mm et 16,67 kPa.

Dans chaque cas, les résultats ont montré la cohérence du rapport de la résistance à l'avancement au bau, à la longueur et au rapport longueur/bau, et leur bonne corrélation avec ceux des programmes précédents qui ont approfondi l'influence de la longueur de la section médiane (MIDBODY) et du coefficient de frottement (FRICTION). Il sera donc possible d'améliorer la tenue aux glaces par une optimisation du rapport longueur/bau du navire.

L'analyse des composantes de la résistance totale, définie comme étant la somme vectorielle des composantes de rupture et de dégagement des débris, n'a dégagé aucune tendance claire permettant d'identifier la composante la plus sensible aux variations paramétriques de longueur ou de forme de proue. Le résultat est que l'on remette en question la part donnée aux composantes de rupture et de dégagement dans les analyses comportant des grandeurs sans dimensions.

Outre l'Arctic, un autre navire, le Nordic, ayant une proue comparable à celle de l'Arctic et un rapport longueur/bau intermédiaire a fait l'objet d'essais sur maquette dont les résultats ont été comparés aux résultats des programmes antérieurs. L'absence de corrélation constatée a été attribuée à la forme particulière de la proue du Nordic qui comporte un dévers en sa partie médiane et un coude à la ligne de flottaison.

Le rapport formule des recommandations que l'on peut résumer comme suit:

a) La méthode d'analyse utilisée dans cette recherche, élaborée par M. B. Colbourne de l'IDM, est couramment appliquée à cet Institut. Or, elle procède d'une démarche différente de celle à la base des programmes MIDBODY et FRICTION. D'après les constatations faites à l'issue de la présente recherche, on

craint que chacune de ces méthodes d'analyse ne produise des résultats singulièrement différents. Il est donc recommandé qu'une méthode d'analyse standard soit élaborée à partir d'une analyse des résultats de tous les essais sur maquettes effectuées à l'IDM.

b) La caractérisation des glaces-modèles utilisées doit se faire suivant une méthode standard améliorée, applicable à tous les essais sur maquettes. Cette méthode, qui est sur le point d'aboutir, fait appel à l'Indexer, appareil étudié et réalisé par Melville Shipping et mis au point avec le concours de l'IDM et du Centre de développement des transports. L'Indexer devrait servir d'outil standardisé pour la caractérisation des glaces-modèles servant aux essais sur maquettes.

c) La mise en équation des rapports existant entre formes de coque et résistance à l'avancement devrait se poursuivre, en insistant sur la composante rupture de la résistance totale et sur les facteurs d'échelle établissant la correspondance entre données théoriques et données réelles. Il semblerait que le mode de rupture de la glace durant les essais sur maquettes, c'est-à-dire la taille et l'orientation des pointes, ait une forte influence sur le facteur d'échelle et sur la composante rupture. Il est recommandé que cette influence soit mesurée, en fonction de l'allure de la maquette, de la résistance de la glace et de son épaisseur, et qu'elle soit comparée à celle qui se dégage des données en vraie grandeur tirées des essais à bord de l'Arctic. Les facteurs d'échelle pourront ainsi être définis avec plus de précision.

d) Le programmme MIDBODY est le troisième d'une série dessais sur maquette livrant des résultats cohérents aux architectes navals. L'étape logique suivante dans ce processus de recherche serait d'approfondir l'influence du parametre rayon de giration autour de l'axe longitudinal sur la résistance à la marche. Les programmes MIDBODY et BEAM ont permis d'approfondir l'influence de deux des variables dimensionnelles: la longueur de la section rectangulaire de la coque et la largeur du bau. La troisième variable d'importance serait celle du déplacement, comme le montre le comportement de la maquette lorsqu'elle pénètre dans les glaces, lequel est influencé par le rayon de giration autour de l'axe longitudinal. Il est proposé de soumettre la maquette de l'ARCTIC et d'un autre navire à des essais visant à mettre en évidence l'influence de ce paramètre sur la résistance à la marche. Au début, la maquette sera complètement guidée et, par la suite, on réduira graduellement les rayon de giration. Les résultats de cette recherche, conjugués aux résultats des essais antérieures avec la maquette de l'ARCTIC permettra de mesurer l'influence de l'inertie de la maquette sur sa résistance à la marche.

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# 1. INTRODUCTION

The MV ARCTIC was built in 1978 as a 28,000 DWT bulk carrier, classed to the Canadian Arctic Shipping Pollution Prevention Regulations (ASPPR) Class 2. Following extensive redesign and construction, the ship was converted to an OBO (OIL/BULK/ORE) carrier in the winter of 1984/85 and upgraded to equivalent ASPPR Class 4 notation in the winter of 1985/86. The upgrade to equivalent ASPPR Class 4 included the construction of a new bow. The new bow, known as the Melville bow, was designed and model tested in three different ice tanks during 1982 to 1984. Following the conversion the ship was tested in the spring of 1986. The full scale trials demonstrated a significant improvement in the ship's icebreaking capability.

One explanation for this improvement was the breaking action of the new bow which tended to create a wider channel than the original hull form and, as a result, reduce the contact and associated crushing between the ship's parallel midbody and the ice. Three model test programs have been undertaken to investigate this phenomenon in more detail. The first program reviewed the influence of the friction coefficient on the bow and midbody (Melville 1987). This is referred to in the remainder of this report as the "FRICTION" program. The second program investigated the influence of parallel midbody length on resistance and how this is affected by friction coefficient and two different bow forms, represented by the original ARCTIC bow and the Melville bow (Melville 1988). This is referred to as the "MIDBODY" program. The objective of the third test program, described in this report, is to determine the effect on icebreaking resistance of midbody breadth and length/breadth variations. This is referred to as the "BEAM" program. The project will also attempt to find a correlation between these tests and previous ice model tests from the ARCTIC. In addition to the three ARCTIC hull forms, a fourth hull form,"NORDIC", having a similar bow form to the M.V. ARCTIC and an intermediate length/breadth ratio, was also included for comparison.

The BEAM program makes use of a 1:30 scale model of the ARCTIC and two parametric beam variations of the same hull form, 20 percent wider and 20 percent narrower. Each model consists of 3 or 4 sections; one bow, one or two midbodies and one stern. The three segmented models permit a length and beam variation analysis and a matrix of length/breadth ratios.

The body of the report is divided into four sections. The first section describes the model tests and reviews the data collection procedures. The second section presents the relationship between resistance, breadth, length and length/breadth ratios. The third and fourth sections present the conclusions and recommendations arising from the work.

# 2. MODEL TESTS

## 2.1 General

A number of model configurations were tested. The base model is the existing ARCTIC, at a scale of 1:30, referred to as the "Base Beam, Base Midbody". This model was also tested with an additional midbody section and is referred to as the "Base Beam, Long Midbody". The second model is a copy of the base model with a 20% wider beam. This was tested with the same length as the "Base Beam, Base Midbody" and is referred to as the "Increased Beam, Base Midbody" and without a midbody section, referred to as the "Increased Beam, Short Midbody". The third configuration was a copy of the base model with a 20% narrower beam. This was tested with the same length as the "Base Beam, Base Midbody" referred to as the "Decreased Beam, Base Midbody" and two shorter lengths referred to as "Decreased Beam, Intermediate Midbody" and "Decreased Beam, Short Midbody".

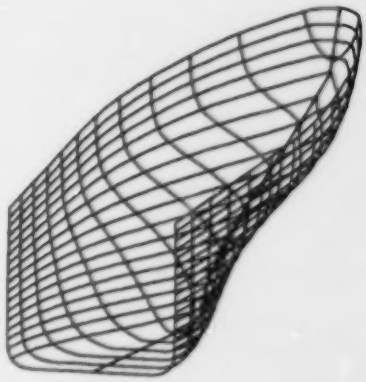
The model tests were conducted in the ice tank of the Institute for Marine Dynamics (IMD) in St. John's, Newfoundland (Jones 1987). A new fibreglass and foam "Base Beam Stern" was built for this program to replace the existing damaged stern. The seven parts for the increased and decreased beam models were constructed of foam and fibreglass using standard IMD procedures. Figure 2.1 presents a perspective view of each model bow. Figures 2.2 and 2.3 present the model's body and waterline plans. Since the models were only increased in beam there is no change to the profile.

The model tests consisted of 7 towed resistance tests in model EG/AD/S ice (Timco 1985) representative of 0.9 m, 500 kPa full scale ice. The original beam model was also tested in model ice equivalent to 1.2 m, 500 kPa full scale ice for correlation with previous model tests (Melville 1984, 1987 and 1988). These full scale ice thicknesses and strengths correspond to 30 mm and 40 mm and 16.67 kPa model ice respectively.

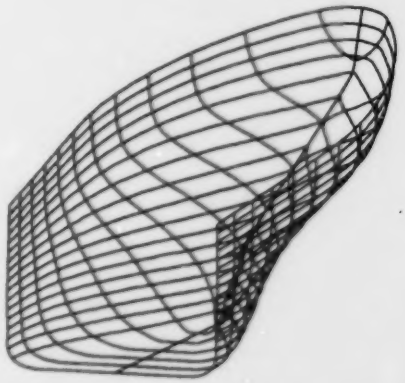
FIGURE 2.1

BEAM VARIATION MODEL TEST PROGRAM

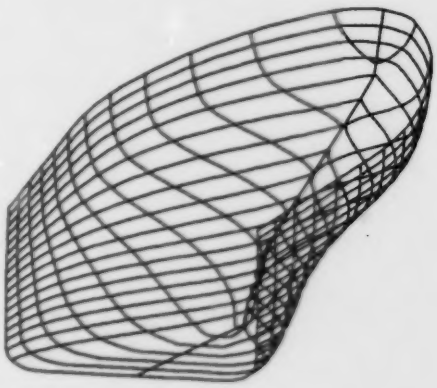
PERSPECTIVE VIEWS



DECREASED BEAM



BASE BEAM

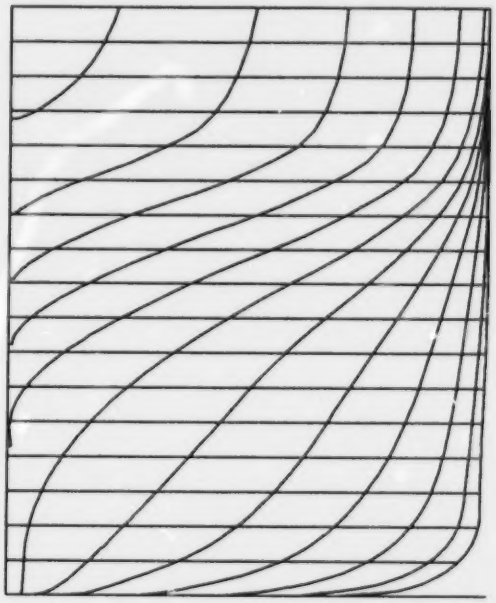


INCREASED BEAM

FIGURE 2.2

BEAM VARIATION MODEL TEST PROGRAM

BODY PLANS



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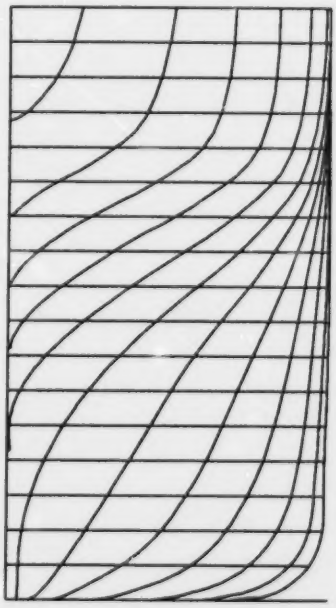
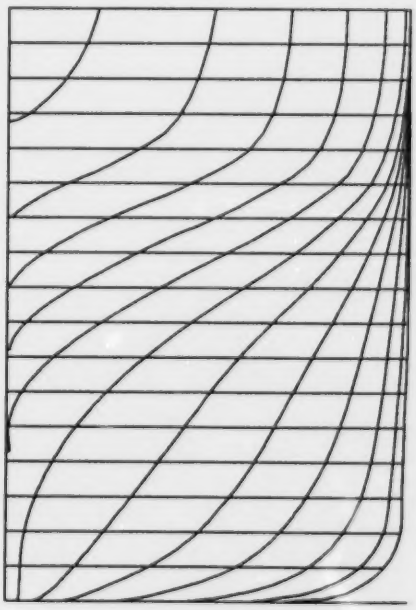


DECREASED BEAM

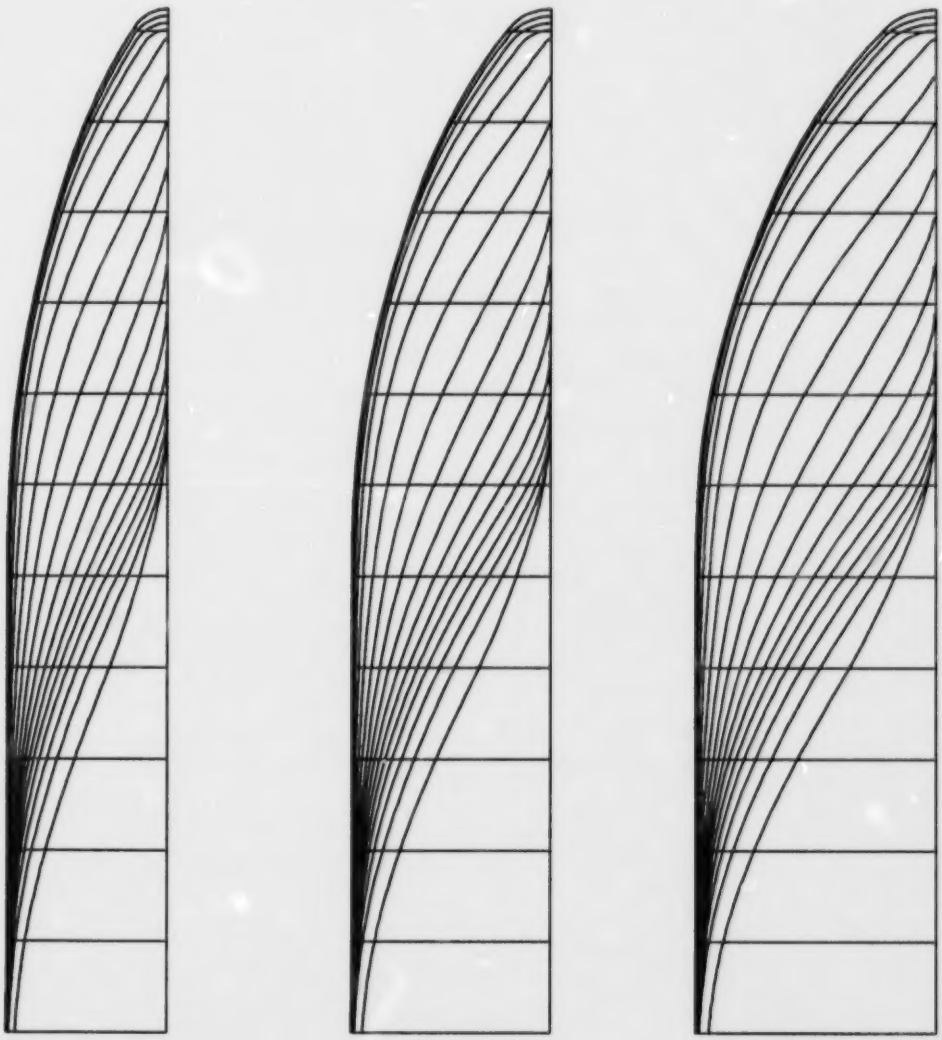


BASE BEAM

FIGURE 2.3

BEAM VARIATION MODEL TEST PROGRAM

WATERLINES



DECREASED BEAM BASE BEAM INCREASED BEAM

## 2.2 Model Test Program and Test Plan

The test program was conducted to investigate the influence of length, breadth and length/breadth ratios on the resistance of an icebreaker. The individual tests are summarized in table 2.1 and described in the following notes:

Base Beam - Base Midbody

This is a test with the ARCTIC model that represents the existing ship. The test is one of two base case correlations with previous test results. The L/B is 9.02 and the model was tested in 30 mm ice thickness.

Decreased Beam - Base Midbody

The existing beam of the ARCTIC (22.86 m) is reduced by about 20 percent to 18.34 m with no change to the length or draught. The resultant L/B is 11.27 and can be correlated with the previous MIDBODY program (Long Ship, L/B = 11.29) and with the results from the "Base Beam - Long Midbody" test of this program discussed below. Ice thickness is 30 mm.

Decreased Beam - Intermediate Midbody

The model with the reduced beam is tested after removing part of its midbody section. The resultant ship is 164.9 m long, 18.34 m beam, and has an L/B of 9.01. This result can be correlated with the results of the base ship discussed above and with the results from the MIDBODY program (Base Ship, L/B = 9.02) Ice thickness is 30 mm.

Decreased Beam - Short Midbody

The midbody section is removed from the reduced beam model, resulting in a length of 137.5 m and an L/B of 7.51. This is correlated with the results from the "Increased beam -Base Midbody" test, discussed below and with the results from the MIDBODY program (Short Ship 2, L/B = 7.52).

## TABLE 2.1

### FULL SCALE DIMENSIONS OF TEST PROGRAM MODELS

| TEST # | BEAM (m) | Length (m) | L/B ratio | Description |
|---|---|---|---|---|
| 1 | 22.86 | 206.2 | 9.02 | Base Beam, Base Midbody |
| 2 | 18.34 | 206.2 | 11.27 | Decreased Beam, Base Midbody |
| 3 | 18.34 | 164.9 | 9.01 | Decreased Beam, Intermediate Midbody |
| 4 | 18.34 | 137.5 | 7.51 | Decreased Beam, Short Midbody |
| 5 | 22.86 | 206.2 | 9.02 | Base Beam, Base Midbody |
| 6 | 22.86 | 258.0 | 11.29 | Base Beam, Long Midbody |
| 7 | 27.49 | 206.2 | 7.52 | Increased Beam, Base Midbody |
| 8 | 27.49 | 160.4 | 5.85 | Increased Beam, Short Midbody |

Base Ship - Thicker Ice

The results of the MIDBODY program thickness variation tests proved to be difficult to interpret, largely due to anomalies in the 40 mm ice sheet. To address this problem, to provide a more reliable understanding of the influence of ice thickness on resistance and to enable subsequent analyses to be conducted in this program, the base case model is tested in a 40 mm model ice sheet (1.2 m full scale).

Original Beam - Long Midbody

The model of the existing ARCTIC is lengthened with additional parallel midbody resulting in a length of 258.0 m and an L/B of 11.29. This is the second base case correlation with the previous MIDBODY program (Long Ship, L/B = 11.29). Ice thickness is 30 mm.

Increased Beam - Base Midbody

The existing beam of the ARCTIC is increased by about 20 percent to 27.49 m with no change to the length or draught. The L/B is 7.52 and may be correlated with the previous MIDBODY program (Short Ship 2, L/B = 7.52) and with the results of the "Decreased beam - Short Midbody" test of this program discussed above. Ice thickness is 30 mm.

Increased Beam - Short Midbody

The model with the increased beam is tested after removing its midbody section. The resultant ship is 160.4 m long with a beam of 27.49 m, resulting in an L/B of 5.85. This is compared with the results from the MIDBODY program (Short Ship 1, L/B = 5.85). Ice thickness is 30 mm.

Table 2.2 illustrates the matrix of L/B ratios obtained from the FRICTION, MIDBODY and BEAM series.

The model test program was conducted during January and February of 1989, using standard test procedures that may be summarized as follows;

a) Ice flexural strength and elastic modulus recorded prior to the model test,

b) Continuous model tests down the centre of the tank at four target speeds; 0.19, 0.33, 0.47 and 0.6 m/sec corresponding to 1, 1.8, 2.5 and 3.3 m/sec at full scale,

c) Ice sheet thickness and flexural strength measurements,

d) Preparation for the presawn ice tests, consisting of "stapling" the existing broken ice sheet and cutting the presawn ice floe pattern,

e) Presawn ice tests down the south side of the ice tank at the same speeds and parallel to the conventional level ice tests,

f) Flexural strength measurements.

Details of each test and associated procedure is presented in the Model Test Report, Appendix B. The measured mechanical and physical properties of the ice sheet and model condition are also presented in the Model Test Report.

## TABLE 2.2

### MATRIX OF L/B RATIOS OBTAINED FROM THE MIDBODY, FRICTION AND BEAM TESTS

| Test Name | Beam (m) | Length (m) | L/B Ratio |
|---|---|---|---|
| Beam | 27.49 | 160.4 | 5.85 |
| Midbody | 22.86 | 133.35 | 5.85 |
| Beam | 18.34 | 137.5 | 7.51 |
| Beam | 27.49 | 206.2 | 7.52 |
| Midbody | 22.86 | 171.87 | 7.52 |
| Beam | 18.34 | 164.9 | 9.01 |
| Beam, Friction and Midbody | 22.86 | 206.2 | 9.02 |
| Beam | 18.34 | 206.2 | 11.27 |
| Beam and Midbody | 22.86 | 258.0 | 11.29 |

## 2.3 Model Test Results

### 2.3.1 Data Overview

A total of 8 ice sheets were tested with target thicknesses of 30 and 40 mm and a target strength of 25 kPa. The model tests normally result in an actual test strength in the range of +/- 25% of the target value. As a result, the target test strength has been assigned to 25 kPa to avoid very low strengths that would result in questionable data. Experience has shown that a target strength of 25 kPa will result in actual ice strengths not lower than 18 kPa. A target strength lower than 25 kPa may result in lower values approaching the unacceptable (<15 kPa). The ice thicknesses recorded through the tests are the mean of several samples. All of the calculated mean values are within 8% of the target ice thickness.

The flexural strength recorded through the test program ranged from 17 kPa to 30 kPa which is a -32% to +20% deviation from the 25 kPa target strength. These ice strengths are within an acceptable range and, based on previous experience, should not provide erroneous results.

The friction coefficient between the ice and the model was calculated for each test. The standard method for calculating the friction coefficient is to measure the horizontal force necessary to slide a test board, which has the same surface as the model, beneath an ice sample. The test procedure and results are presented in the Model Test Report (Appendix B). The friction measurements resulted in a number of friction coefficients discussed in the Detailed Model Test Analysis, Appendix C, and presented in Appendix B.2. The friction values were 0.1 for the Base Beam models, 0.12 for the Decreased Beam models and 0.07 for the Increased Beam models.

In addition to using the friction jig, tests were also conducted directly on the midbody sections. Tests were conducted with a plate supported on the model to test the panels in the same configuration as the model segments. This resulted in a friction coefficient of 0.065 for a plate that tested as 0.069 using the jig in the normal configuration. This would indicate that the modified test arrangement yields consistent friction results with the conventional procedure.

### 2.3.2 Data Correction

The model tests were all conducted with target ice thicknesses, strengths and friction coefficients, however, as with any physical testing, the target values were not always obtained. To permit comparisons between different ice sheets there are standard correction procedures that have been used.

These standard correction procedures may be summarized as;

a) Ice thickness; The correction to the subject test is calculated from the percentage rate of change of resistance and thickness and the difference between the target and measured ice thickness. The percentage rate of change of resistance with thickness is calculated from tests of the same model in two different ice thicknesses at the same speed. This correction is usually small due to the small deviations between the target and measured ice thicknesses

b) Ice strength; Based on presawn, or zero strength, ice tests the percentage rate of change of resistance with ice strength is calculated. The correction to the subject test is calculated from an assumed linear relationship between measured and zero ice strength.

c) Friction coefficient: The rate of change of resistance with friction coefficient is calculated based on tests with the same model, at the same speed, with different friction coefficients. This relationship was developed during the MIDBODY and FRICTION programs. Two series of tests were used, one with the model of the existing ARCTIC in 50 mm ice and a second with a model of a shortened ARCTIC in 30 mm ice. The major difference between these tests is the high speed dependency exhibited by the 50 mm tests that was not observed in the 30 mm tests. These relationships are illustrated in figures 2.4 and 2.5. The correction to the subject test is calculated by using the percentage change in resistance as a function of friction coefficient.

It is conventionally assumed that the measured resistance data is normalized for thickness and strength separately. The alternative is to apply corrections to the resistance values that include previous corrections. The result of this calculation will depend on which correction is applied first. This has been discussed in a previous report (Melville 1987) in which the results from two similar ice sheets were compared using the two methods. The result of this comparison indicated that data tended to give less consistent results when applied with multiple corrections, independent of which was applied first. As a result, all subsequent adjustments to the data in this report are calculated from the algebraic sum of the strength and thickness corrections and the measured resistance.

The correction to the data for the friction coefficient is applied following the strength and thickness corrections.

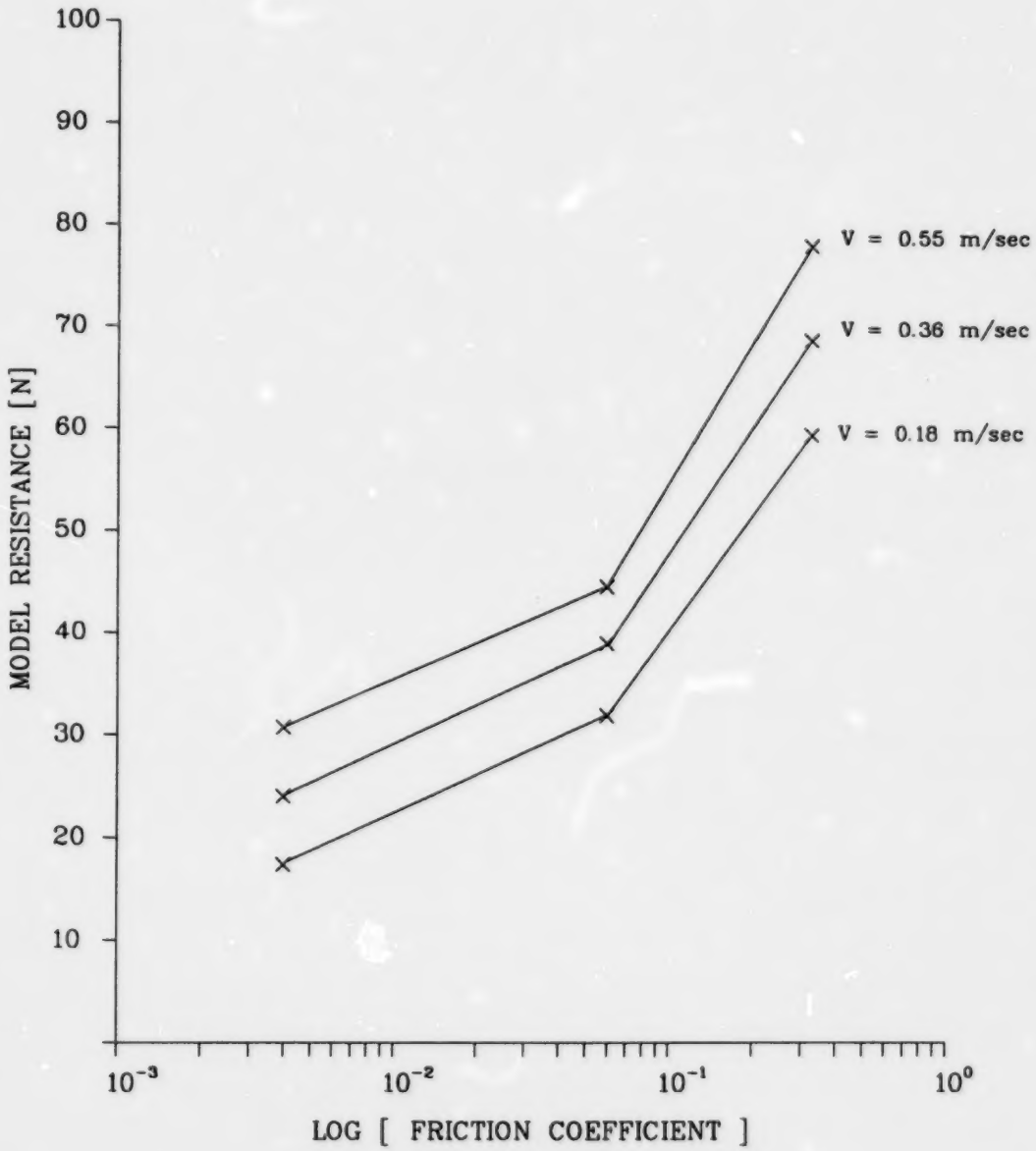
Following these corrections to the raw data, it is possible to compare the results with identical tests from previous model test programs. This comparison is described in detail in Appendix C and illustrated in figures 2.6 and 2.7

It may be noted that during the original analysis of the MIDBODY test program data a series of corrections were made based on relationships between thickness, strength, speed and resistance. These corrections have now largely been supported by the BEAM series of tests and confirm the validity of this type of analysis. Figures 2.6 and 2.7 contain a number of points that were modified, the 0.18 m/sec point in 30 mm ice and the 40 mm MIDBODY test data on figure 2.6 and the 0.47 m/sec point on figure 2.7. In all cases the comparison between the MIDBODY, FRICTION and BEAM programs have demonstrated that this form of analysis is correct and results in more representative values.

The necessity for this type of analysis, which is largely due to unusual measured ice strengths, highlights the short falls in the current manual strength measuring methods adopted in ice tanks and the growing need for more precise and consistent measuring equipment.

FIGURE 2.4

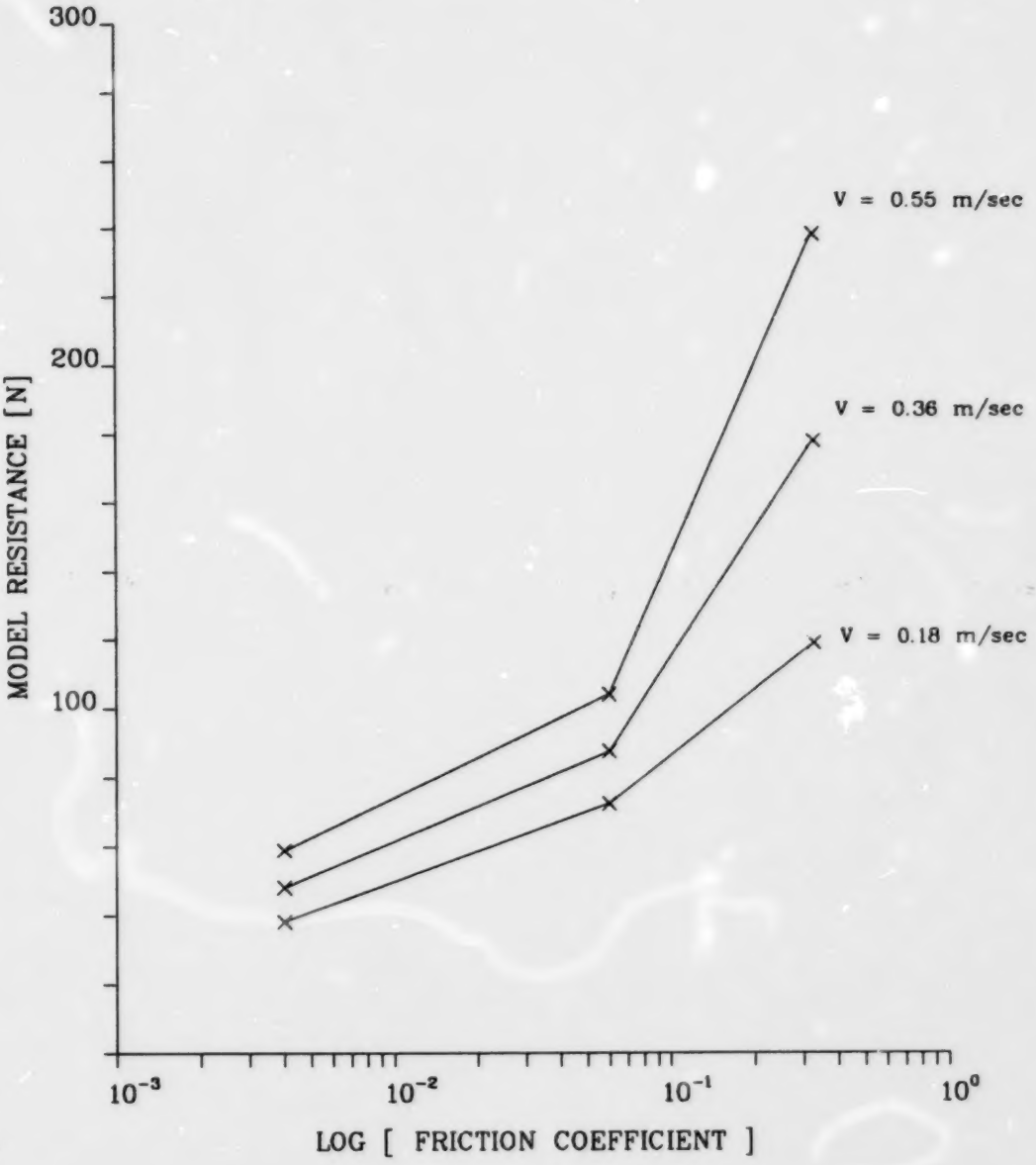
RESISTANCE vs FRICTION COEFFICIENT FOR THE MELVILLE BOW ON THE SHORT MIDBODY MODEL




Target Ice Thickness = 30 mm
Target Ice Strength = 16.67 kPa
Friction Coefficient = 0.004, 0.06 and 0.33

FIGURE 2.5

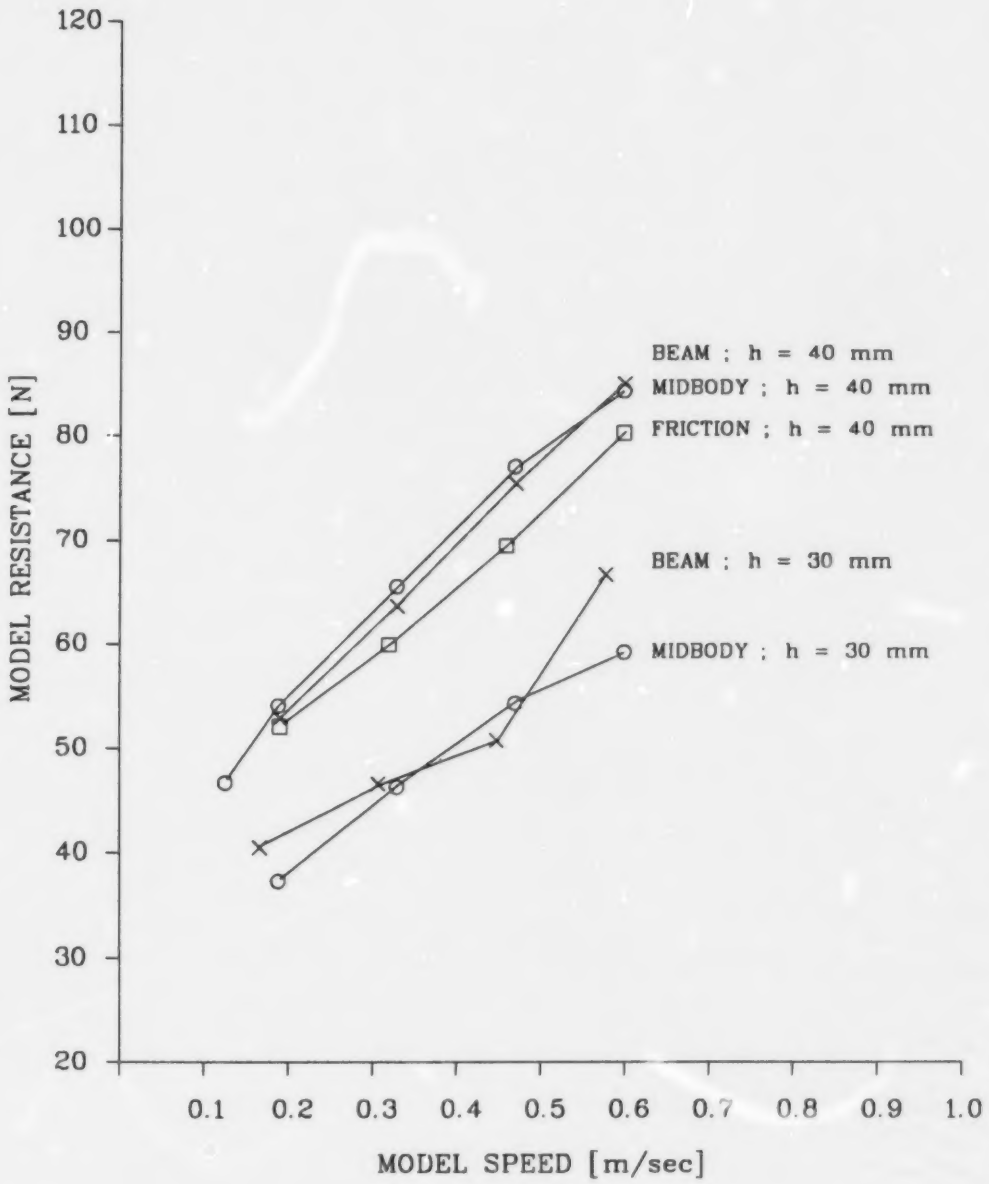
RESISTANCE vs FRICTION COEFFICIENT FOR THE MELVILLE BOW ON THE ARCTIC MODEL




Target Ice Thickness = 50 mm
Target Ice Strength = 16.67 kPa
Friction Coefficient = 0.004, 0.06 and 0.33

FIGURE 2.6

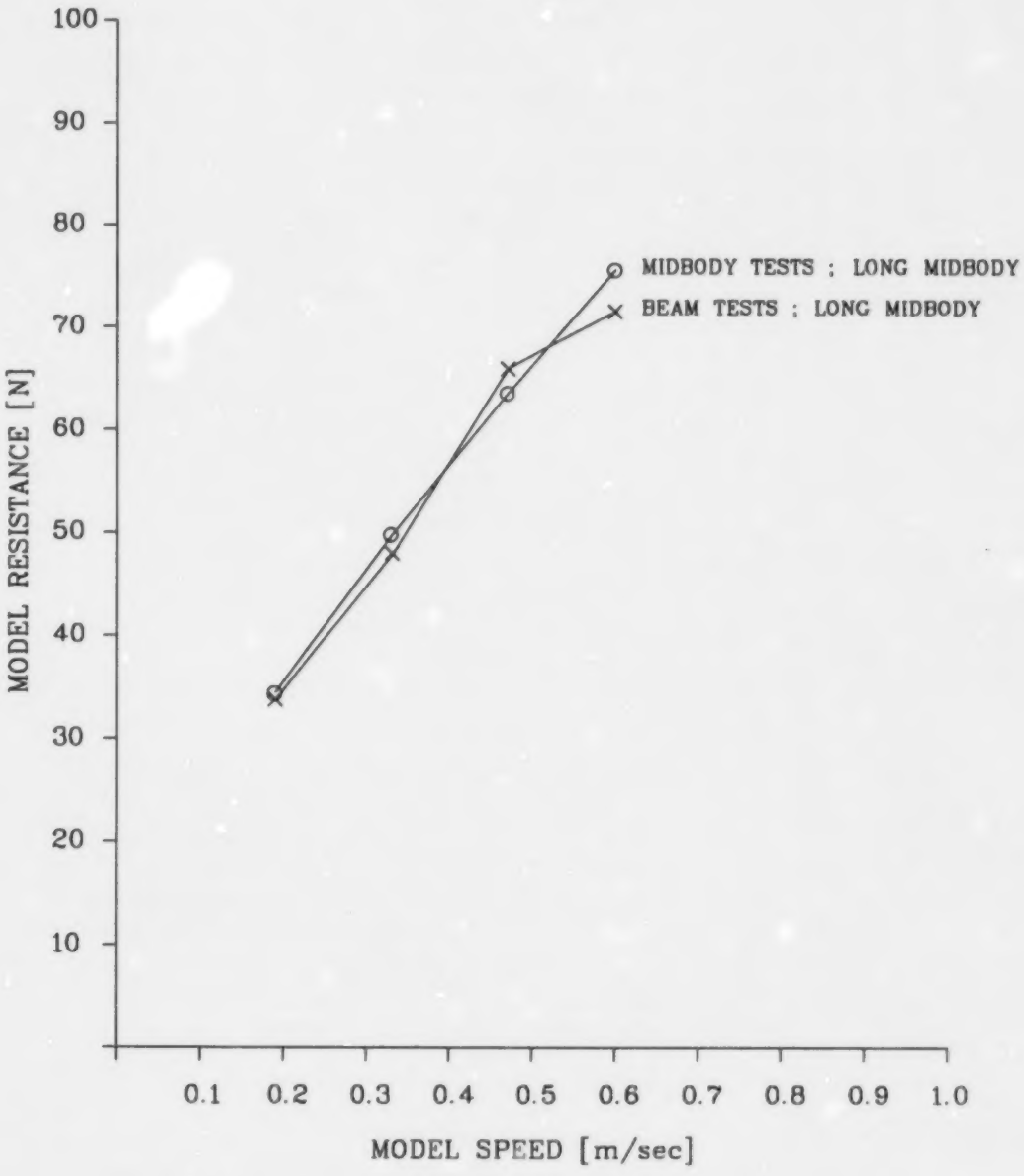
CORRECTED MODEL RESISTANCE vs SPEED FOR THE BEAM MIDBODY AND FRICTION TEST PROGRAMS




Target Ice Thickness = 30 and 40 mm
Target Ice Strength = 16.67 kPa
Target Friction Coefficient = 0.06

FIGURE 2.7

MODEL TEST RESISTANCE vs SPEED FOR THE LONG MIDBODY BASE BEAM ; MIDBODY AND BEAM TESTS




Target Ice Thickness = 30 mm
Target Ice Strength = 16.67 kPa
Target Friction Coefficient = 0.06

# 3. DATA ANALYSIS

## 3.1 General

There are two methods that may be adopted to analyze the data. Each data point may be reviewed individually or the data set may be collectively analyzed with a regression analysis. The advantage with the regression analysis is that the numbers are easier to manipulate. The disadvantage is that it does not recognise clear problems with the data such as irregular variations of resistance with speed and ice thickness. Recognising this, the data was first reviewed with respect to consistency, Appendix C and then, based on this analysis, analyzed using the regression approach to simplify data manipulations.

The data analysis procedure that is used throughout the remainder of the report has been developed by Dr. Bruce Colbourne of the Institute for Marine Dynamics (IMD) and is presented in the model test report. Model scale values have been scaled using FROUDE scaling laws to full scale values for all the following analysis. It should also be noted that the results presented below have been derived from the BEAM, MIDBODY and FRICTION test programs. Appendix A presents the complete data set and the analysis to derive the nondimensional coefficients.

In addition to the FRICTION, MIDBODY and BEAM test programs the results of another icebreaking vessel, referred to as the "NORDIC", with a comparable bow form have also been incorporated into the analysis.

The data analysis may be summarized as:

a) The effect of Length and Beam on resistance; Resistance is plotted against ship length and beam for the range of models, over a range of speeds.

b) The effect of L/B ratio on resistance; The model tests are presented as a series of length to breadth ratio tests with each model configuration adjusted to a constant water plane area. Resistance is plotted as a function of L/B ratio for various speeds. Adjusting the scale also changed the ice thicknesses and strengths and these were corrected to 0.9 m and 500 kPa respectively using the data correction procedure discussed in the Model Test Report.

The analysis presented here is slightly different from the analysis presented in the MIDBODY report. The MIDBODY report presented the different hulls at a constant displacement to assess the different combinations of length and breadth and their relationship with resistance. This analysis required the calculation of the scale to generate the same full scale displacement for each model. The analysis presented in this report is intended to fulfil the same objective with the exception that, instead of displacement, the waterplane area is used as the full scale target variable. The waterplane area was selected in lieu of the displacement to eliminate the influence of draught which is generally considered to have a small influence on resistance but was a significant factor in the normalisation for displacement. As a result the relationships described in the following sections should only be used recognizing that the influence of draught on resistance may or may not be significant.

## 3.2 Resistance vs Length and Beam

The combined BEAM, MIDBODY and FRICTION test programs permit three length variations with the decreased beam model, four length variations with the original beam model and two length variations with the increased beam model. Figures 3.1, 3.2 and 3.3 present the results as Ship Resistance vs. Ship Length for the range of beams tested at 1.0, 2.0 and 3.0 m/sec respectively.

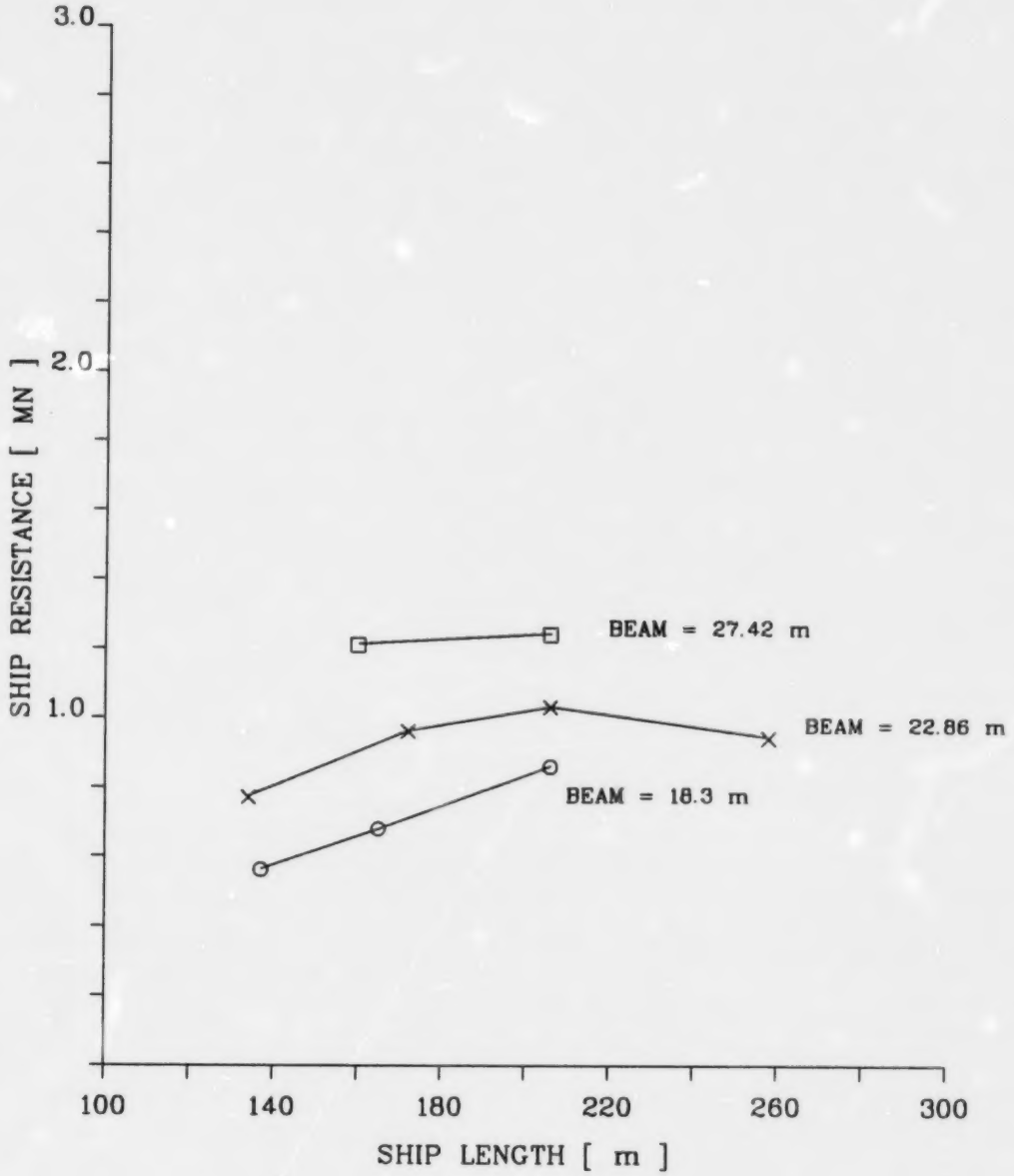
The overall trend demonstrates a general increase in resistance as a function of length for all three beam configurations. The exception to this result is the Base Beam, Long Midbody model which, at low speeds, yields a reduction in resistance with a length increase of 206.16 to 258 m ( 25% increase in length ) of 9% and, at higher speeds, yields an increase of resistance of 24%. Considering the uniformity and trends of the remaining data it may be observed that the low speed data point appears to be too low and the high speed data point too high.

Table 3.1 tabulates the percentage increase and (decrease) of resistance between the models as a function of length. The percentage increase and (decrease) in resistance as a function of beam is shown in table 3.2.

FIGURE 3.1

RESISTANCE vs. LENGTH FOR A RANGE OF BEAMS

AT 1.0 m/sec



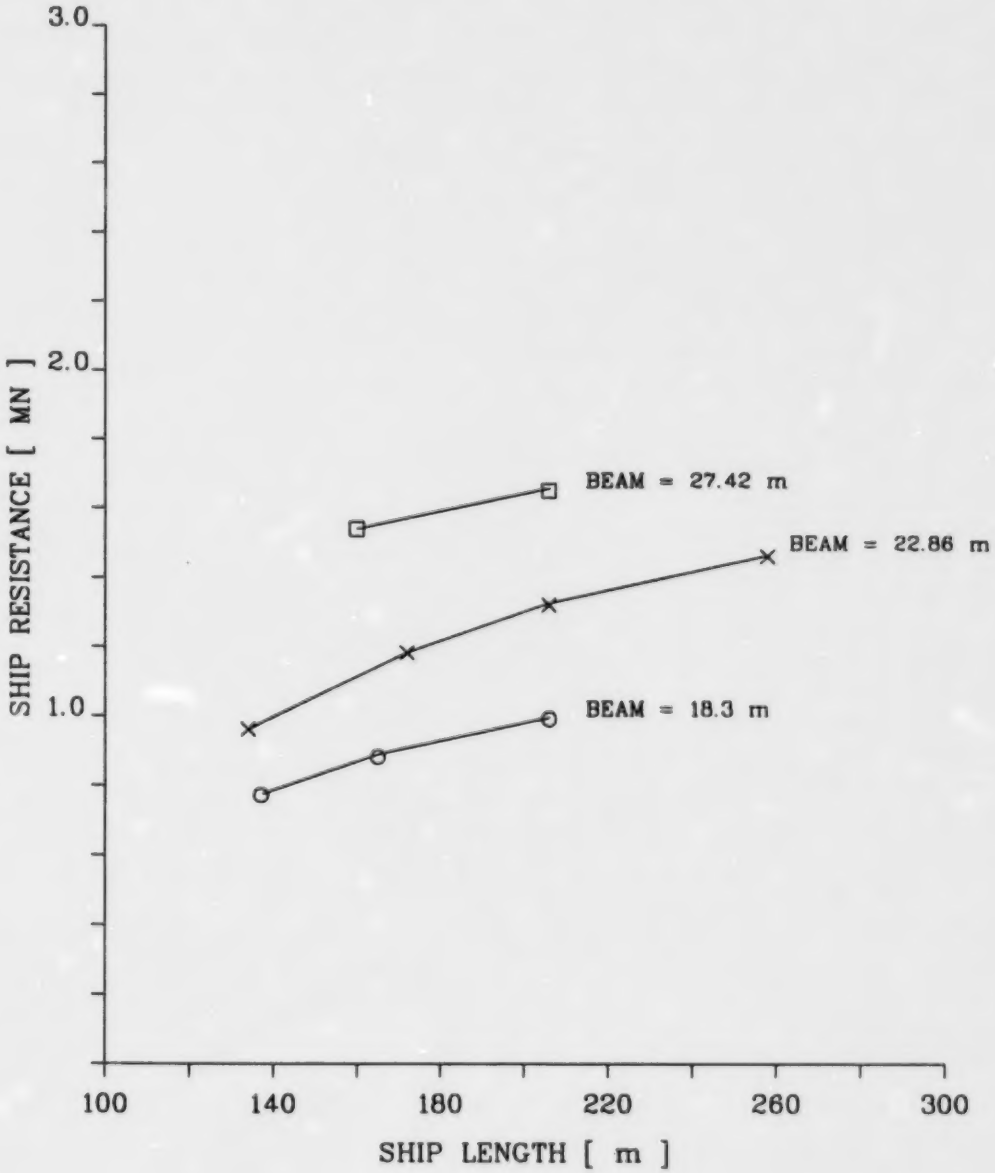

Ice Thickness = 0.9 m

Ice Strength = 500 kPa

Friction Coefficient = 0.06

FIGURE 3.2

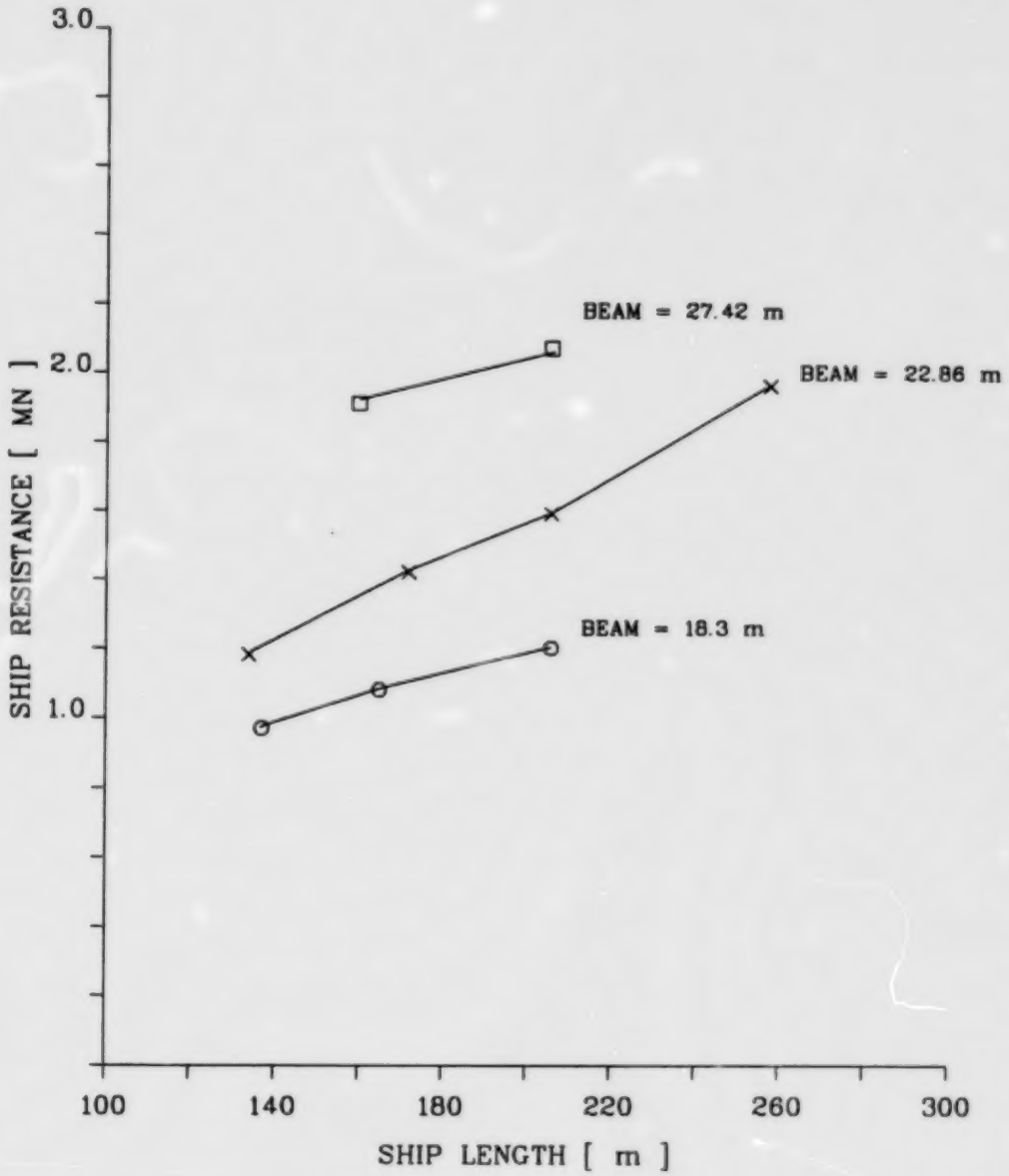
RESISTANCE vs. LENGTH FOR A RANGE OF BEAMS AT 2.0 m/sec




Ice Thickness = 0.9 m
Ice Strength = 500 kPa
Friction Coefficient = 0.08

FIGURE 3.3

RESISTANCE vs. LENGTH FOR A RANGE OF BEAMS AT 3.0 m/sec




Ice Thickness = 0.9 m
Ice Strength = 500 kPa
Friction Coefficient = 0.06

## TABLE 3.1

### INFLUENCE OF LENGTH ON RESISTANCE AS A FUNCTION OF BEAM AND SPEED

| Beam [m] | Speed [m/sec] | Ship Length Variation and Percentage Increase (Decrease) in Resistance | | |
|---|---|---|---|---|
| | | 137 to 164 m | 164 to 206 m | 206 to 258 m |
| 18.3 | 1 | 21% | 26% | ***26%*** |
| | 2 | 13% | 13% | ***14%*** |
| | 3 | 12% | 11% | ***13%*** |
| | | 133 to 172 m | 172 to 206 m | 206 to 258 m |
| 22.86 | 1 | 24% | 8% | ( 9%) |
| | 2 | 22% | 12% | 11% |
| | 3 | 20% | 12% | 24% |
| | | | 160 to 206 m | |
| 27.42 | 1 | | 3% | |
| | 2 | | 7% | |
| | 3 | | 8% | |

Note: Italic bold notation denotes that the data point was derived by interpolation from the existing data.

## TABLE 3.2

### INFLUENCE OF BEAM ON RESISTANCE AS A FUNCTION OF LENGTH AND SPEED

| Length (m) | Speed (m/sec) | Ship Beam Variation and Percentage Increase (Decrease) in Resistance | |
|---|---|---|---|
| | | 18.3 to 22.86 m | 22.86 to 27.42 m |
| 133.8 | 1 | 41% | ***29%*** |
| | 2 | 27% | ***22%*** |
| | 3 | 24% | ***19%*** |
| 171.9 | 1 | ***35%*** | ***27%*** |
| | 2 | ***32%*** | ***33%*** |
| | 3 | ***28%*** | ***38%*** |
| 206.0 | 1 | 21% | 20% |
| | 2 | 33% | 25% |
| | 3 | 32% | 30% |
| 258 | 1 | ***(13%)*** | ***35*** |
| | 2 | ***29%*** | ***21*** |
| | 3 | ***44%*** | ***14*** |

Note: Italic bold notation denotes that the data point was derived by interpolation from the existing data.

Figures 3.4, 3.5 and 3.6 present the results of the tests as a function of Resistance vs Ship Beam over a range of Lengths at 1, 2 and 3 m/sec respectively. The results discussed above in the length variation review can also be identified in these figures. In addition to the data points, lines have been drawn on the figures that represent constant length, calculated from extrapolating the existing data points. These can be seen to represent the data set very well with the exception of the Base Beam Long Midbody (Beam = 22.86, Length = 258 m) and the Increased Beam Short Midbody tests (Beam = 27.42, Length = 160).

At low speeds the Base Beam Long Midbody test appears to have a low resistance, in figure 3.4 the 258 m long ship has a lower resistance than the 172 and 206 m long ships. At higher speeds the same model appears to have a relatively high resistance, in figure 3.6 the resistance is well above the extrapolated resistance calculated from the remainder of the data set. It is interesting to note that the best correlation between the data set appears to occur at 2 m/sec, figure 3.5. The high speed dependency shown by this model manifests itself in table 3.2 as the negative percentage resistance increase from 18.3 to 22.86 m beam at 1.0 m/sec and the high percentage resistance increase for the same beam change at 3.0 m/sec.

It can be seen from figures 3.4 to 3.6 that the Increased Beam tests for the two model lengths tested are almost indistinguishable at low speed, 1.0 m/sec, and appear to conform with the remainder of the data at higher speeds.

In summary it may be noted from these figures and tables that;

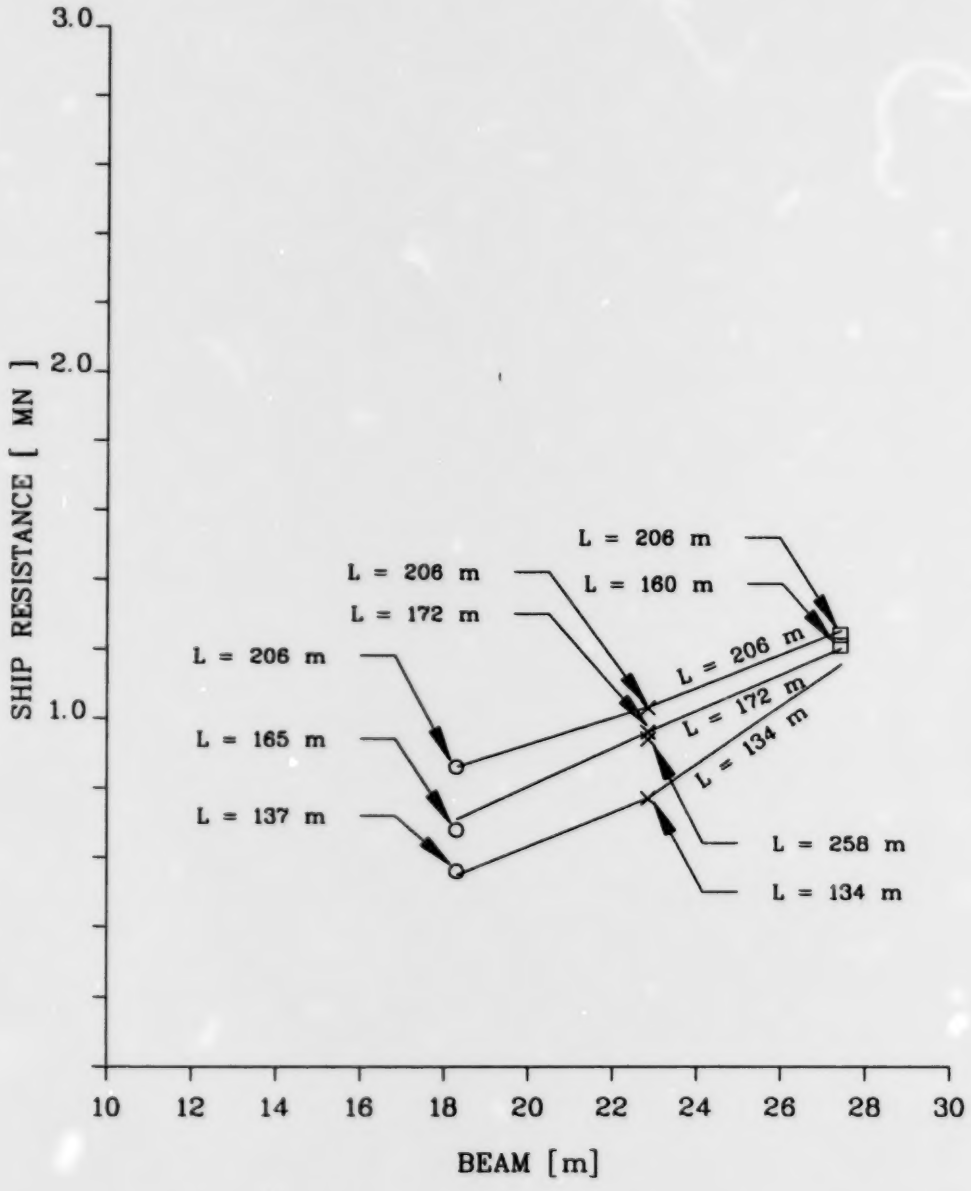
a) With the exception of the Base Beam Long Midbody model there is an increase of resistance with ship length.

b) The percentage change in resistance as a function of ship length (table 3.1) decreases with speed for the Narrow Beam and short Base Beam models and increases with speed for the longer Base Beam and Wide Beam models.

c) Based on the interpolated and extrapolated lines from figures 3.4 to 3.6 and table 3.2, the percentage change of resistance from the Narrow Beam to the Base Beam, at low speeds as a function of length, reduces for longer ships. This implies that the longer hull form is having a beneficial effect on resistance. This may be rationalised by considering that as the ship length increases the displacement increases, the longitudinal moment to change trim increases and the natural pitching period decreases. All these factors are thought to reduce resistance.

FIGURE 3.4

RESISTANCE vs. BEAM FOR A RANGE OF LENGTHS AT 1.0 m/sec

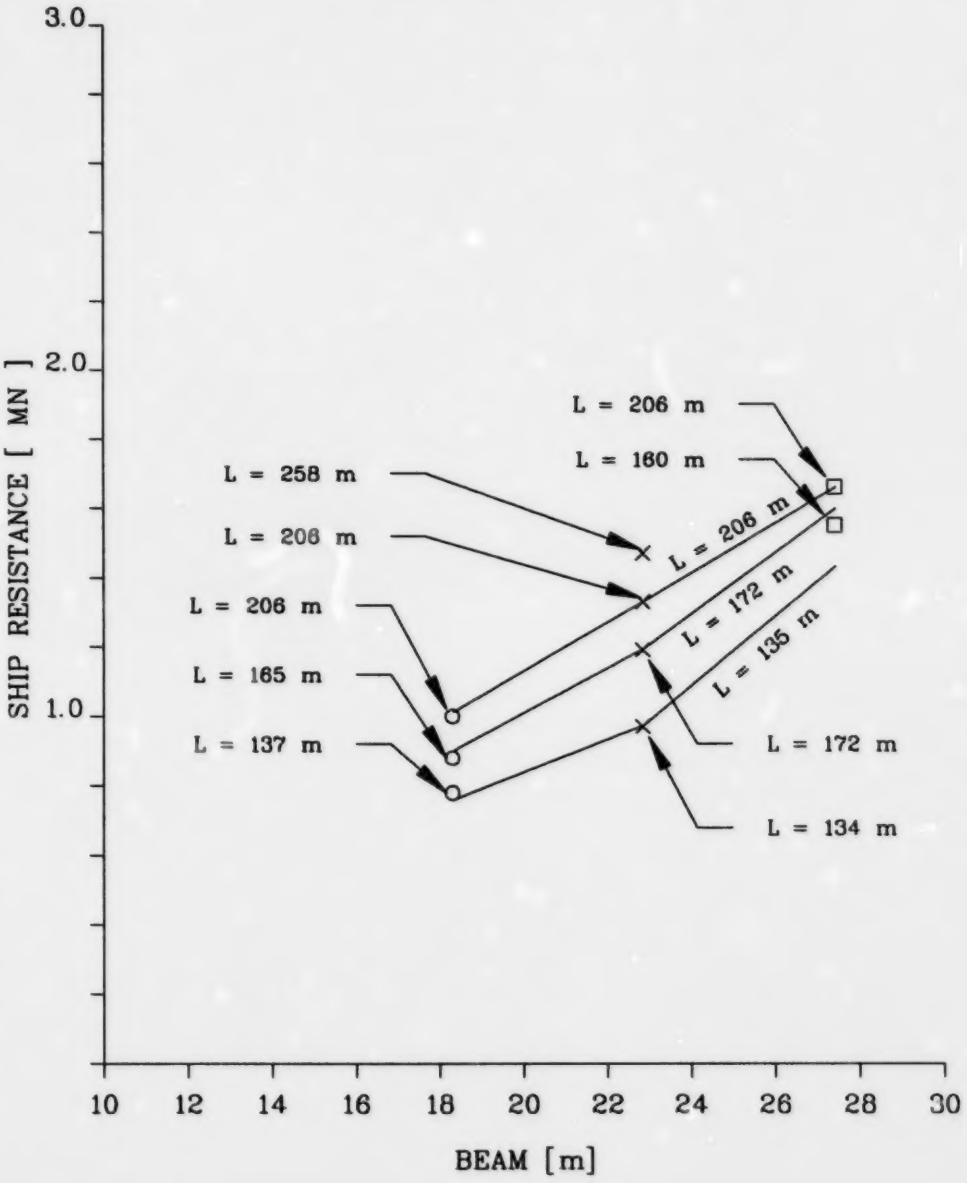



Ice Thickness = 0.9 m
Ice Strength = 500 kPa
Friction Coefficient = 0.06

FIGURE 3.5

RESISTANCE vs. BEAM FOR A RANGE OF LENGTHS

AT 2.0 m/sec

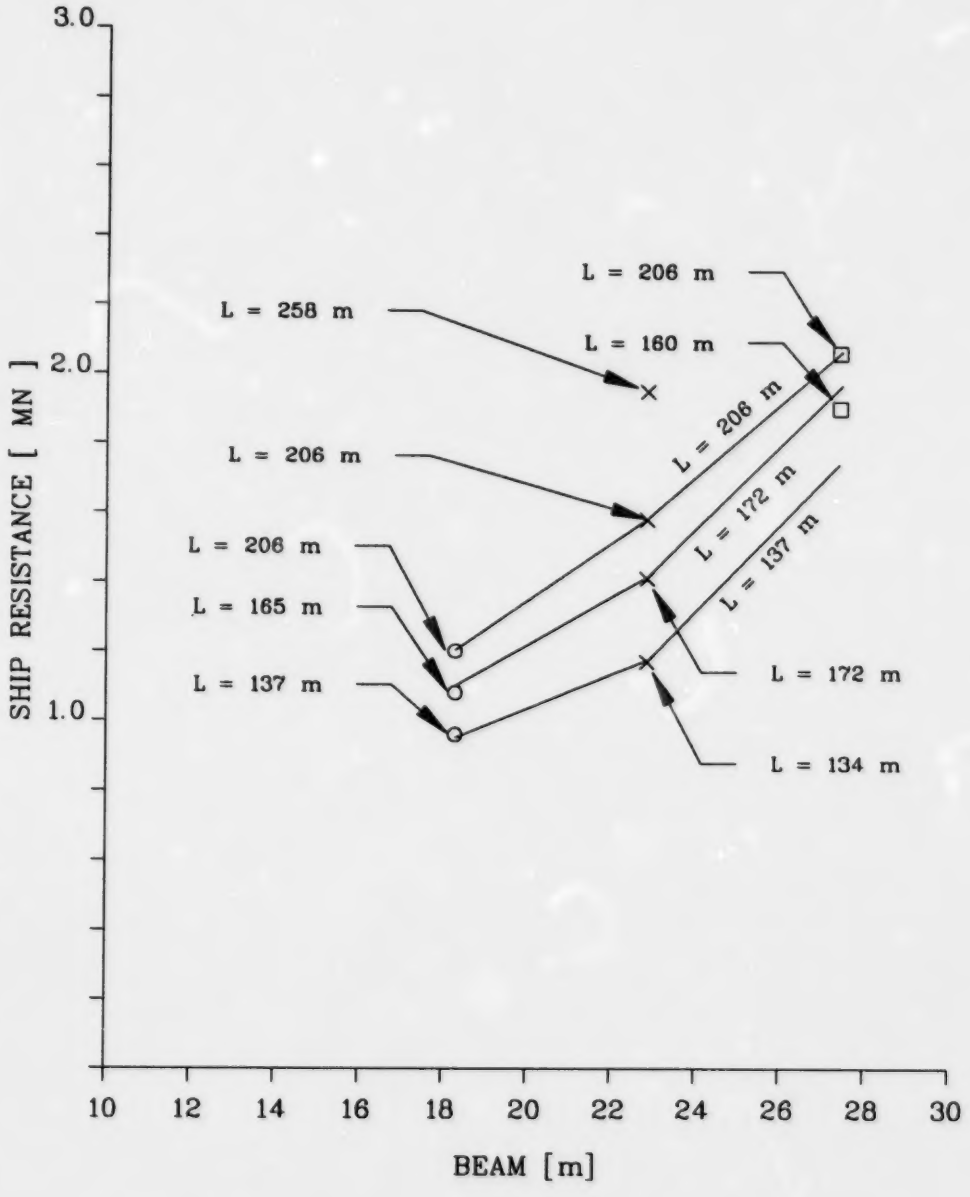



Ice Thickness = 0.9 m
Ice Strength = 500 kPa
Friction Coefficient = 0.06

FIGURE 3.6

RESISTANCE vs. BEAM FOR A RANGE OF LENGTHS

AT 3 m/sec




Ice Thickness = 0.9 m

Ice Strength = 500 kPa

Friction Coefficient = 0.06

d) Based on the interpolated and extrapolated lines from figures 3.4 to 3.6 and table 3.2, the percentage change of resistance from the Narrow Beam to the Base Beam, at higher speeds as a function of length, increases for longer ships. This implies that the longer hull form is having a negative effect on resistance. This is the opposite influence found at low speeds and is considered to be due to the dynamic response of the hull. A review of the pitch displacement for the Base Beam Increased Midbody model indicated that there was almost no influence on either the maximum or average value of pitch displacement as a function of speed. The pitch response for the Base Beam Base Midbody model showed almost a 100% increase in both average and maximum values of pitch. Clearly the shorter model was pitching more at higher speeds and this appears to have had a beneficial influence on resistance. There is no clear explanation of why this should occur since it has been generally accepted that higher pitch response results in lower resistance.

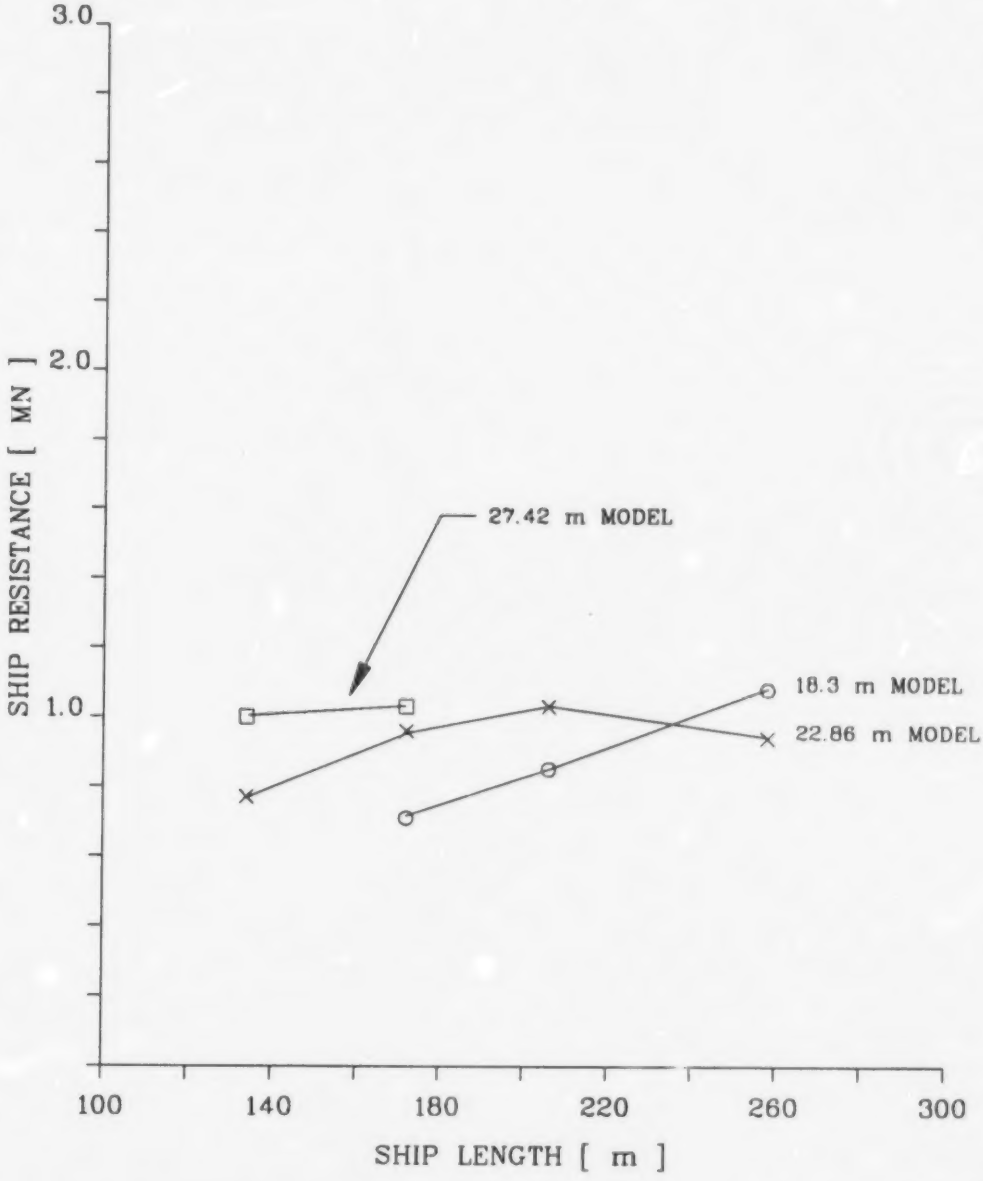
The Resistance vs Length and Beam data discussed above have been taken directly from the test program results and scaled at 1:30. In an effort to investigate the influence of beam in more detail, the scale for each model combination has been adjusted so that the resultant full scale ships have the same beam. Figures 3.7, 3.8, and 3.9 present the data corrected to constant beam as Resistance vs. Length. The same data trends observed for the resistance vs. beam data may also be seen in this data with the high speed dependency of the Base Beam Long Midbody vessel and the small influence of length on the Increased Beam models. Since this data represents ships of constant beam and is plotted against length, the difference between these curves should be only a function of draught, which is considered to be small, and bow form.

The Increased and Decreased Beam models were each created by parametrically increasing or decreasing the beam, as a result the wider models will have higher flare and waterline angles than the base model and, similarly, the narrow beam models will have lower flare and waterline angles. The influence of these slightly different bow forms on the hull angles is illustrated in figure 3.10, which presents the flare and waterline angles for the three bow forms. As a measure of ice transitting performance the Kashteljan and Shimanski coefficients for the two bows are shown in table 3.3

It may be noted that although the wider beam models have higher flare angles, their associated higher waterline angles have the effect of keeping the Kashteljan coefficient constant and increasing the Shimanski coefficient therefore implying a less efficient bow form. This is reflected in the results were the wider beam models are yielding a higher resistance than the narrow beam models. Table 3.4 presents the percentage difference between the results which may, in part, be attributed to bow

FIGURE 3.7

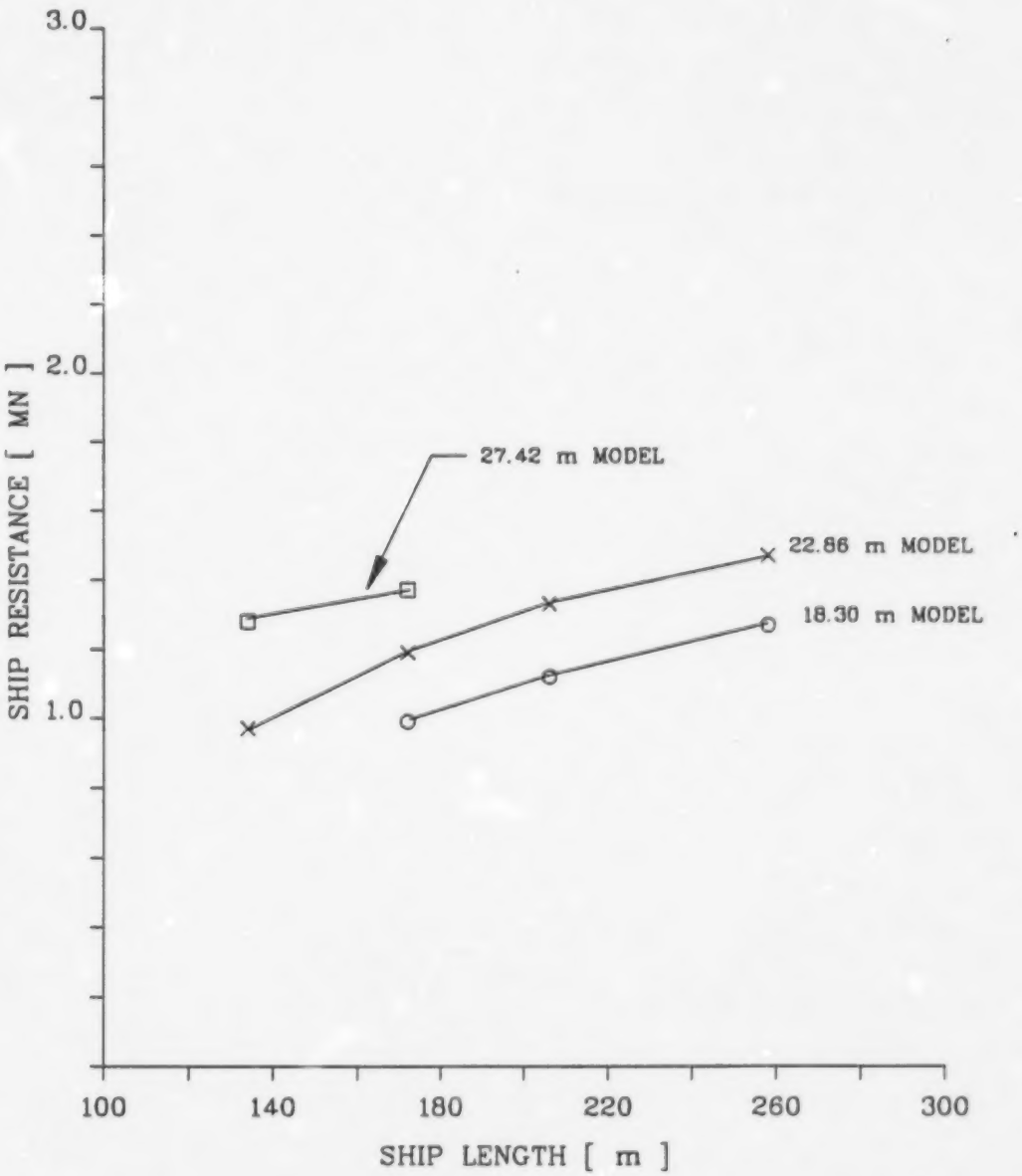
SHIP RESISTANCE vs LENGTH FOR A CONSTANT BEAM OF 22.86 m AT 1.0 m/sec




Ice Thickness = 0.9 m
Ice Strength = 500 kPa
Friction Coefficient = 0.06

FIGURE 3.8

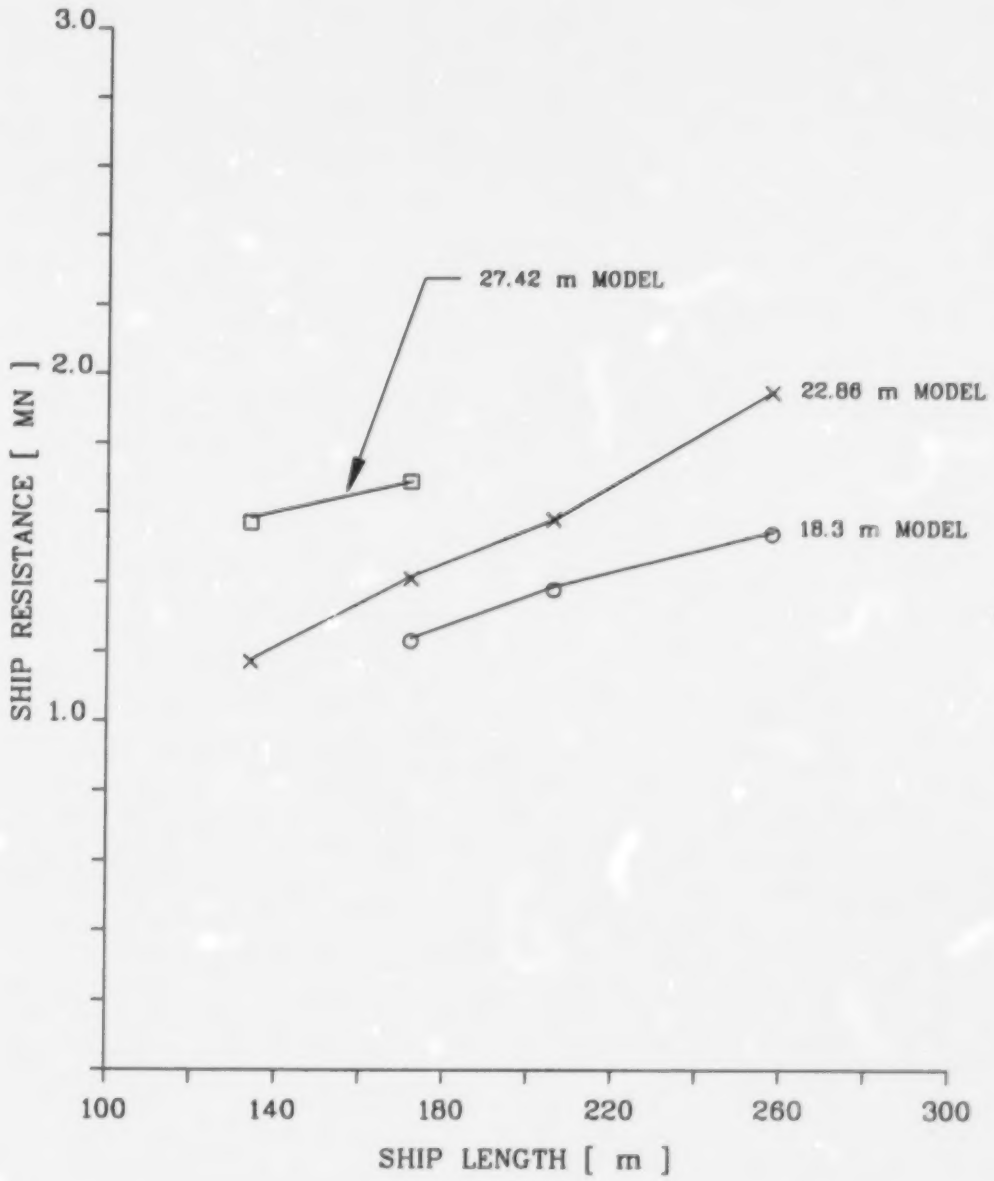
SHIP RESISTANCE vs. LENGTH FOR A CONSTANT BEAM OF 22.93 m AT 2.0 m/sec




Ice Thickness = 0.9 m
Ice Strength = 500 kPa
Friction Coefficient = 0.06

FIGURE 3.9

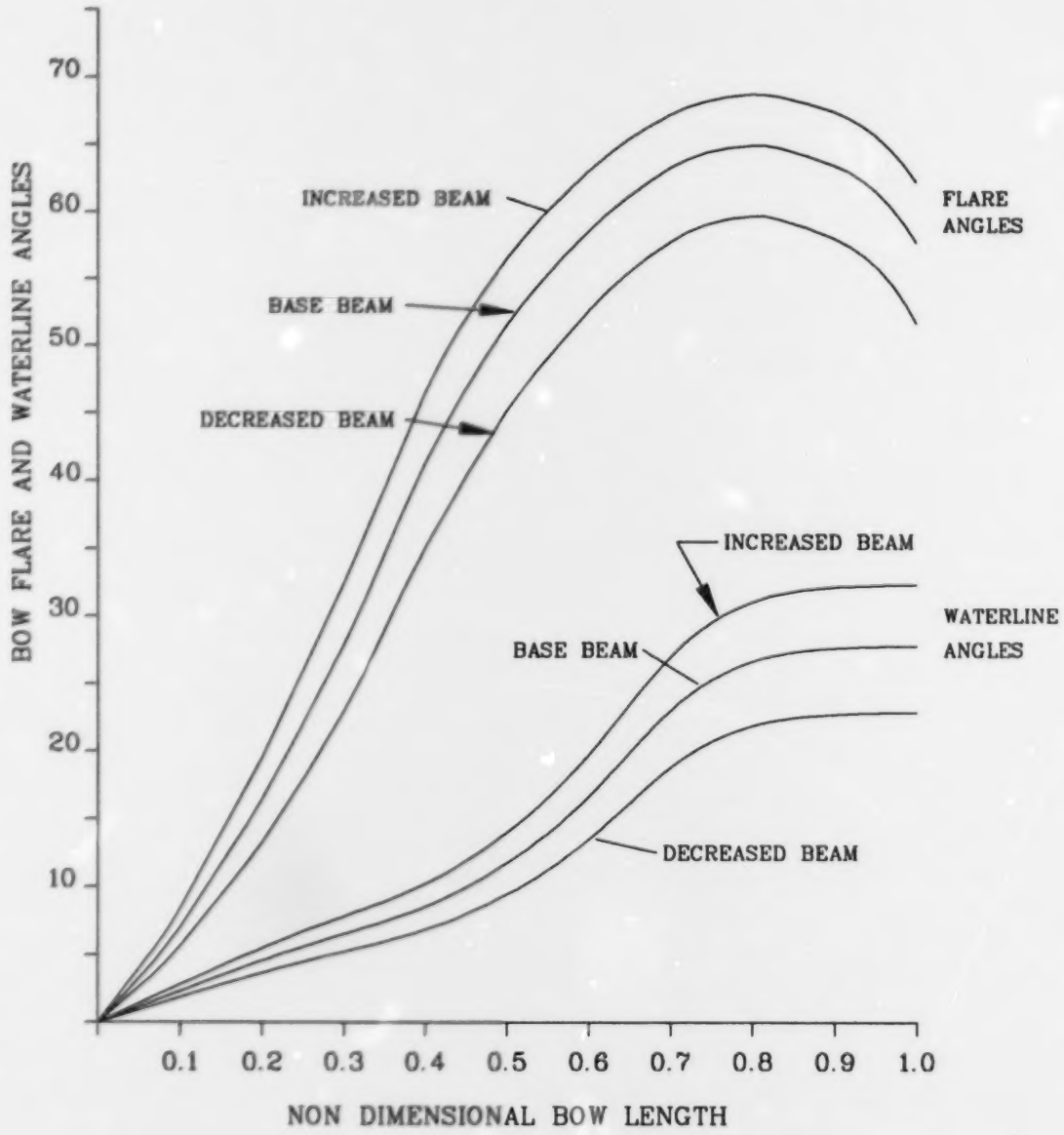
SHIP RESISTANCE vs. LENGTH FOR A CONSTANT BEAM OF 22.86 m AT 3.0 m/sec




Ice Thickness = 0.9 m
Ice Strength = 500 kPa
Friction Coefficient = 0.06

FIGURE 3.10

BOW FLARE AND WATERLINE ANGLES FOR THE BEAM VARIATION TEST SERIES

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## TABLE 3.3

### BOW FORM SHIMANSKI AND KASHTELJAN COEFFICIENTS

| | Kashteljan Coefficient | Shimanski Coefficient |
|---|---|---|
| Increased Beam | 1.24 | 2.73 |
| Base Beam | 1.23 | 3.13 |
| Decreased Beam | 1.24 | 3.72 |

## TABLE 3.4

### PERCENTAGE INCREASE (DECREASE) BETWEEN MODELS CORRECTED TO A CONSTANT BEAM OF 22.86 m

| Length [m] | Speed [m/sec] | Ship Beam Variation and Percentage Increase (Decrease) in Resistance | |
|---|---|---|---|
| | | 27.42 to 22.86 m | 18.3 to 22.86 m |
| 133.8 | 1 | (23%) | |
| | 2 | (24%) | |
| | 3 | (25%) | |
| 171.9 | 1 | ( 7%) | 35% |
| | 2 | (13%) | 21% |
| | 3 | (17%) | 14% |
| 206.0 | 1 | | 21% |
| | 2 | | 19% |
| | 3 | | 14% |
| 258 | 1 | | (13%) |
| | 2 | | 16% |
| | 3 | | 27% |

form differences. Since the bow form coefficients are divided between the "Ice Cutting" Kashteljan coefficient and "Ice Clearing" Shimanski coefficient, it was elected to further subdivide the resistance values in figures 3.7 to 3.9 into their clearing and breaking components as defined by the nondimensional analysis. Table 3.5 presents the results of this analysis.

It can be seen from this table that the change of resistance between the different beams consists of different breaking and clearing components. For example the 23 to 25% reduction in total resistance from the Increased Beam 133.8 m ship to the Base Beam ship consists of a 35 to 39% reduction in the breaking component and a 10 to 12% reduction in the clearing component. This would indicate that the change of bow form has a higher influence on the breaking component than the clearing component. However, if the same beam change is considered for the 171.9 m ship, the total 7 to 17% reduction in resistance consists of a 25 to 22% increase in breaking resistance and a 45% reduction in the clearing resistance.

## 3.3 Resistance vs L/B Ratio

In addition to the results from the ARCTIC model test program, a second hull referred to as the "NORDIC", having a similar bow form and intermediate length/breadth ratio was also included in the analysis.

The results of the ARCTIC model test program and the NORDIC were analyzed with respect to the resistance vs L/B ratio. In order to normalise the relationship each configuration was scaled with the appropriate scale factor to yield a waterplane area equal to the ARCTIC base ship, scaled to 1:30. Table 3.6 presents the resultant resistance for each ARCTIC model and the associated scale ratios and L/B ratios. Figures 3.11, 3.12 and 3.13 present the Resistance vs L/B ratio for each model. It can be seen that the ARCTIC curves have a similar form to the Resistance vs Length curves at a constant beam discussed above. This may be anticipated since the correction to a constant waterplane will be similar to a correction to constant length times breadth and, since length is not considered to have a significant influence, this will be similar to the correction to constant beam.

The curves indicate that the resistance of each L/B configuration is influenced by the beam of the model from which the data was collected. This may be due to a number of reasons;

a) The constant waterplane is achieved by scaling each model to a different scale ratio, therefore it is necessary to have different target model ice thicknesses and

## TABLE 3.5

### PERCENTAGE INCREASE (DECREASE) OF BREAKING AND CLEARING RESISTANCE FOR MODELS CORRECTED TO A CONSTANT BEAM OF 22.86 m

| | | B = 27.42 to 22.86 m Resistance | | L = 18.3 to 22.86 m Resistance | |
|---|---|---|---|---|---|
| Length (m) | Speed (m/sec) | Breaking | Clearing | Breaking | Clearing |
| 133.8 | 1 | (35) | (10) | | |
| | 2 | (38) | (18) | | |
| | 3 | (39) | (12) | | |
| 171.9 | 1 | 25 | (45) | 79 | (17) |
| | 2 | 29 | (45) | 52 | ( 8) |
| | 3 | 22 | (45) | 39 | ( 3) |
| 206 | 1 | | | 25 | 15 |
| | 2 | | | 41 | ( 3) |
| | 3 | | | 51 | (13) |
| 258 | 1 | | | (29) | 22 |
| | 2 | | | 33 | 5 |
| | 3 | | | 91 | ( 4) |

## TABLE 3.6

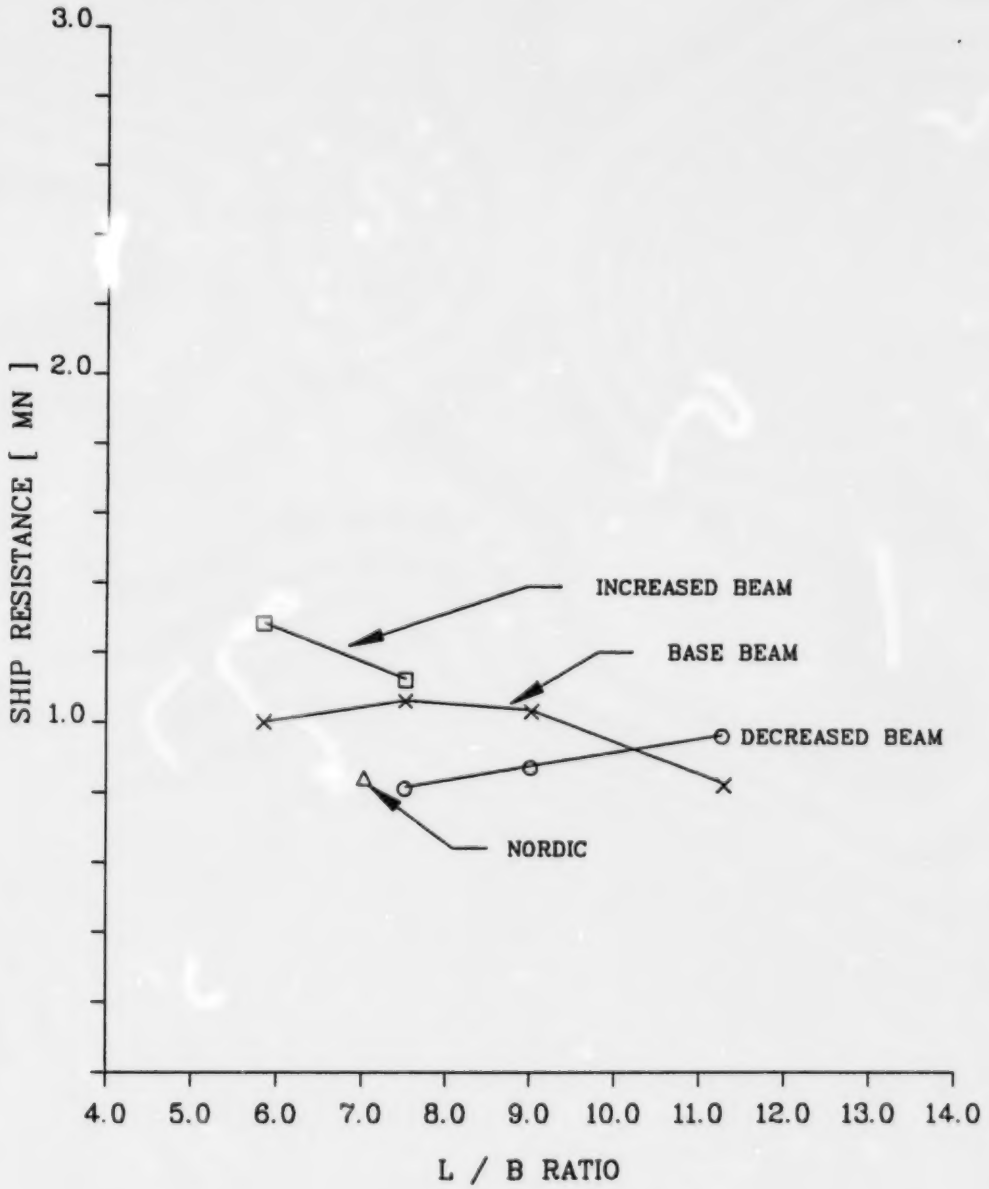
### RESISTANCE FOR MODELS CORRECTED TO A CONSTANT WATERPLANE AREA

| Model Configuration | Model Scale | Length [m] | Beam [m] | L/B Ratio | Speed [m/sec] | Resistance [MN] |
|---|---|---|---|---|---|---|
| Increased Beam | 31.7 | 169 | 28.97 | 5.85 | 1.0 | 1.28 |
| Short Midbody | | | | | 2.0 | 1.65 |
| | | | | | 3.0 | 2.02 |
| Base Beam | 38.76 | 173 | 29.54 | 5.85 | 1.0 | 1.00 |
| Short Midbody | | | | | 2.0 | 1.28 |
| | | | | | 3.0 | 1.56 |
| Decreased Beam | 42.61 | 195 | 25.99 | 7.51 | 1.0 | 0.81 |
| Short Midbody | | | | | 2.0 | 1.13 |
| | | | | | 3.0 | 1.42 |
| Increased Beam | 27.38 | 188 | 25.03 | 7.52 | 1.0 | 1.12 |
| Base Midbody | | | | | 2.0 | 1.51 |
| | | | | | 3.0 | 1.86 |
| Base Beam | 33.33 | 191 | 25.40 | 7.52 | 1.0 | 1.06 |
| Intermediate | | | | | 2.0 | 1.33 |
| Midbody | | | | | 3.0 | 1.58 |
| Decreased Beam | 38.19 | 210 | 23.30 | 9.01 | 1.0 | 0.87 |
| Intermediate | | | | | 2.0 | 1.14 |
| Midbody | | | | | 3.0 | 1.41 |
| Base Beam | 30.00 | 206 | 22.86 | 9.02 | 1.0 | 1.03 |
| Base Midbody | | | | | 2.0 | 1.33 |
| | | | | | 3.0 | 1.58 |
| Decreased Beam | 33.57 | 231 | 20.48 | 11.27 | 1.0 | 0.96 |
| Base Midbody | | | | | 2.0 | 1.13 |
| | | | | | 3.0 | 1.36 |
| Base Beam | 26.44 | 227 | 20.15 | 11.29 | 1.0 | 0.82 |
| Long Midbody | | | | | 2.0 | 1.29 |
| | | | | | 3.0 | 1.70 |

FIGURE 3.11

SHIP RESISTANCE vs. L/B RATIO

FOR CONSTANT WATERPLANE AREA AT 1.0 m/sec




Ice Thickness = 0.9 m

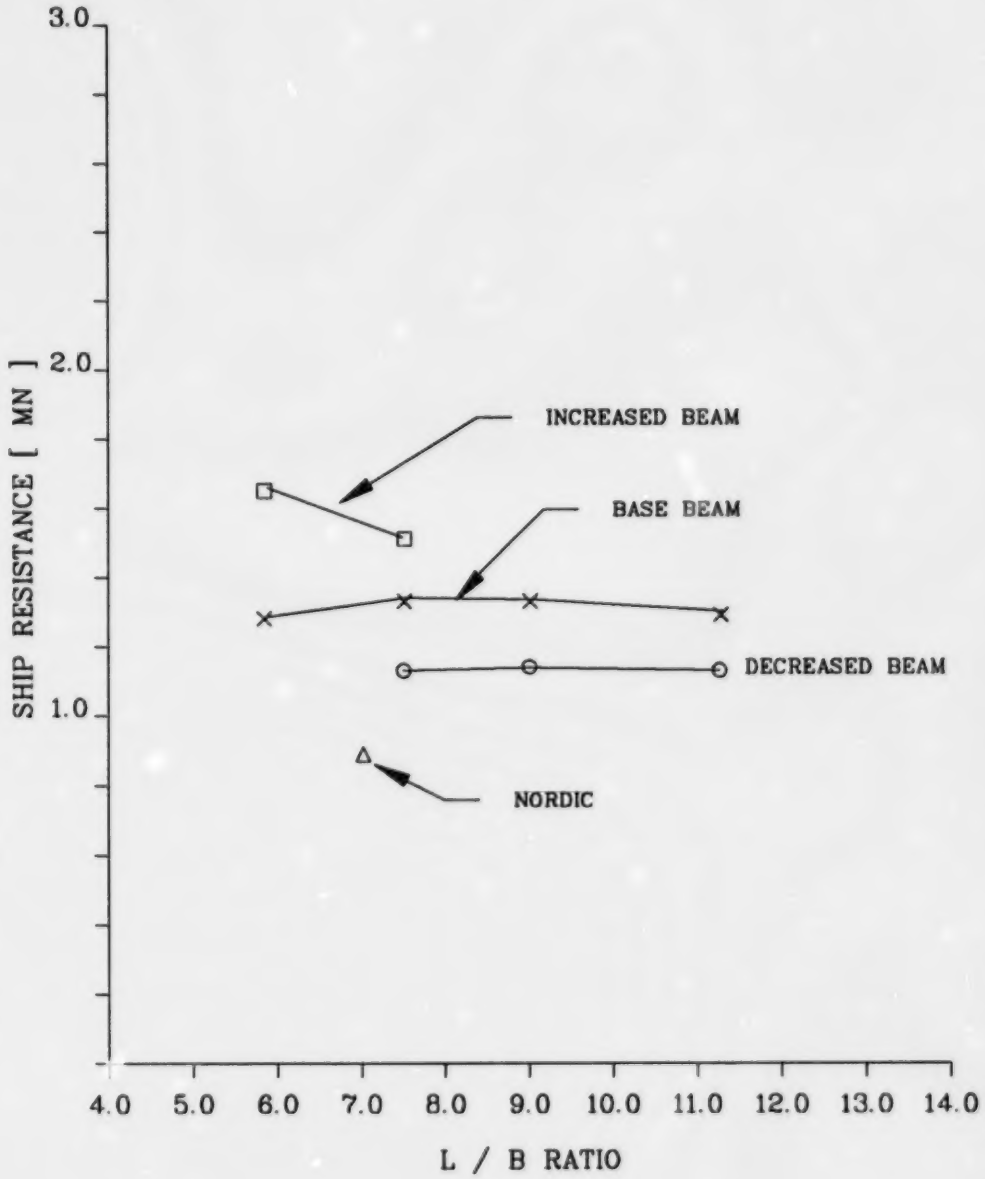
Ice Strength = 500 kPa

Friction Coefficient = 0.06

FIGURE 3.12

SHIP RESISTANCE vs. L/B RATIO

FOR CONSTANT WATERPLANE AREA AT 2.0 m/sec




Ice Thickness = 0.9 m

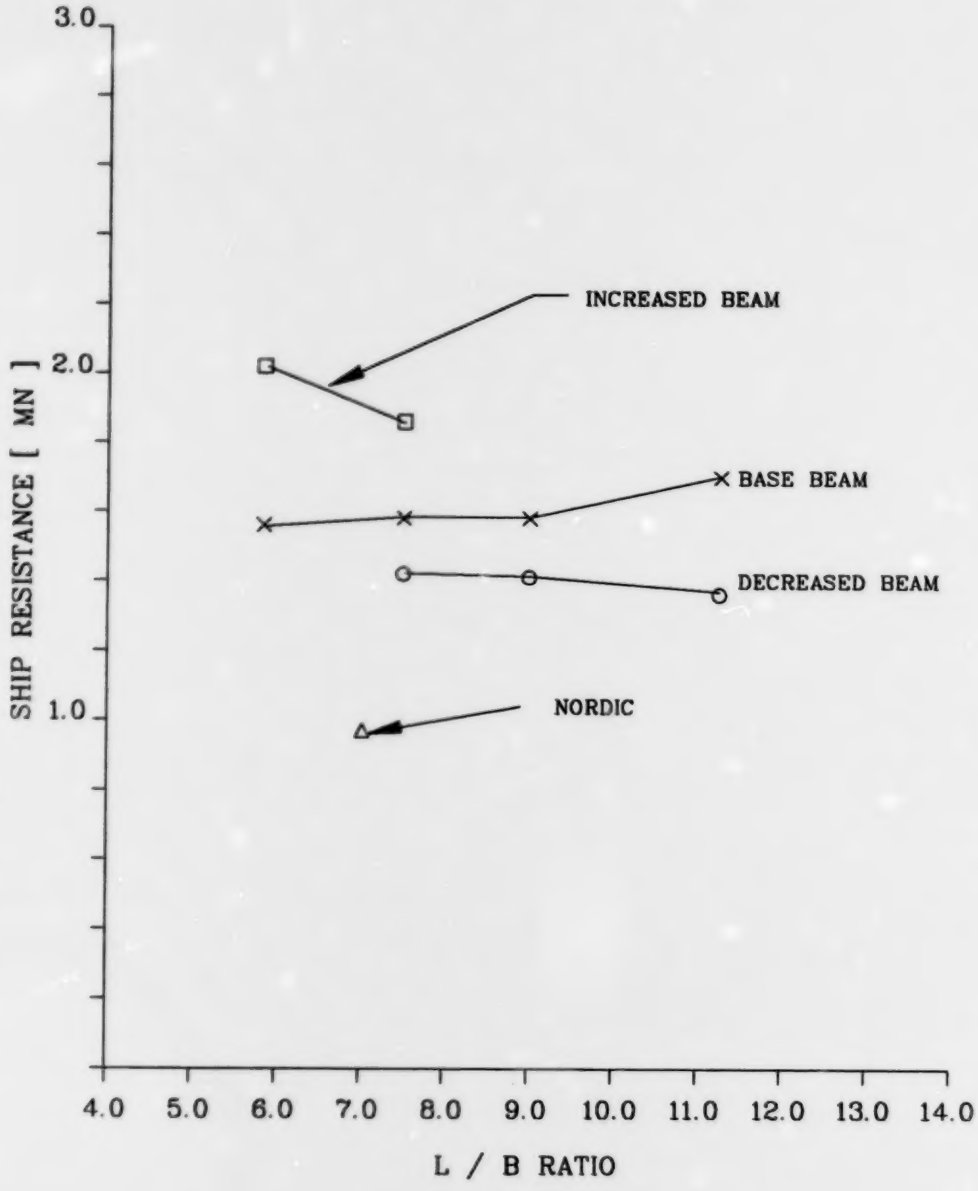
Ice Strength = 500 kPa

Friction Coefficient = 0.06

FIGURE 3.13

SHIP RESISTANCE vs. L/B RATIO

FOR CONSTANT WATERPLANE AREA AT 3.0 m/sec




Ice Thickness = 0.9 m

Ice Strength = 500 kPa

Friction Coefficient = 0.06

strengths to obtain constant full scale thicknesses and strengths. If the correction to target ice thickness and strength is not correct then the target resistance values will be influenced by the scale ratio and therefore the original model beam and length.

b) As discussed above, the different model beams result in different bow forms.

c) Any physical model testing will be associated with errors, with respect to model testing and with current technology, these may be expected to be within about 10 to 20% depending on the test.

The data from the NORDIC does not appear to correlate well with the ARCTIC data. This is particularly true at the higher speeds. At low speeds, figure 3.11, the NORDIC data is within the range of results obtained from the ARCTIC models. However, at higher speeds the NORDIC has an increasingly lower resistance and at 3 m/sec the NORDIC has a resistance about 50% of the ARCTIC models. This relationships illustrates that the NORDIC has a significantly lower rate of increase of resistance with speed than the ARCTIC models. Although the NORDIC has a similar generic bow form and L/B ratio to the BEAM variation models there are two primary differences.

a) The NORDIC has midbody flare.

b) The NORDIC bow includes a knuckle at the waterline which is believed to improve the performance of the hull.

Although it is considered that the hull form and midbody flare contributed to the lower speed dependency of the NORDIC, it was not possible, within the scope of this project, to examine the cause in more detail.

In addition to the data being corrected to a constant waterplane equal to the waterplane of the base ship, each ARCTIC model configuration was also scaled to a waterplane equal to 20% higher and 20% lower than the waterplane area assuming a scale of 1:30. Table 3.7 presents the results of this analysis and, as may be expected, the resistance increases with waterplane area. The percentage change in resistance for the 20% increase and decrease of waterplane area was about 10% and consistent over all the models tested. Figures 3.14 to 3.19 illustrate the Resistance vs L/B relationships for each configuration and three speeds.

## TABLE 3.7

## WATERPLANE AREA VARIATION

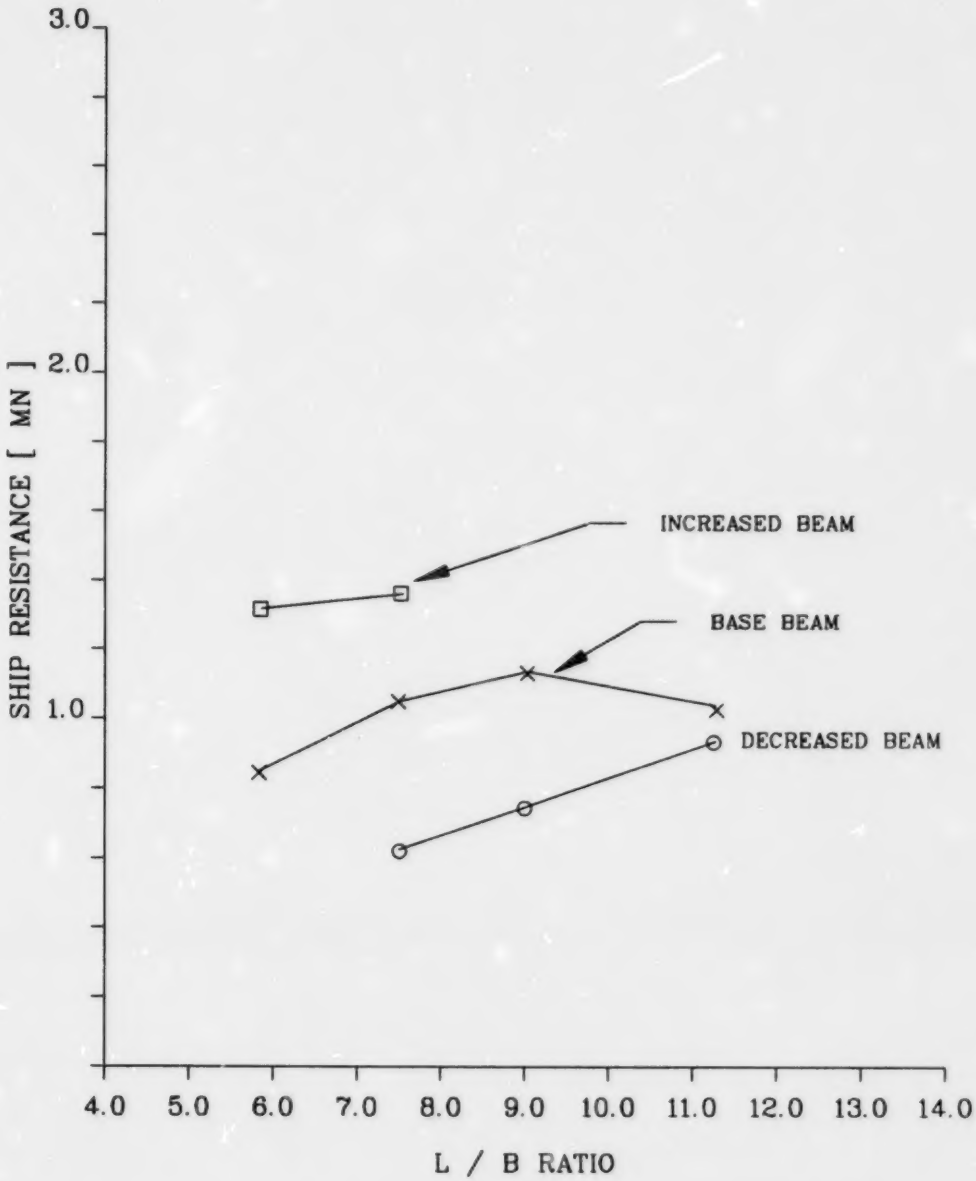
| Model Configuration | L (m) | B (m) | L/B | Resistance [MN] 1 m/sec | Resistance [MN] 2 m/sec | Resistance [MN] 3 m/sec | Waterplane Area [$m^2$] |
|---|---|---|---|---|---|---|---|
| Base Beam Base Midbody | 206 | 22.86 | 9.02 | 1.03 | 1.33 | 1.58 | 4124 |
| +20% | 226 | 25.04 | 9.02 | 1.13 | 1.46 | 1.75 | 4948 |
| -20% | 184 | 20.44 | 9.02 | 0.92 | 1.18 | 1.40 | 3299 |
| Long Beam Base Midbody | 258 | 22.86 | 11.29 | 0.94 | 1.47 | 1.95 | 5309 |
| +20% | 283 | 25.04 | 11.29 | 1.03 | 1.63 | 2.16 | 6371 |
| -20% | 231 | 20.44 | 11.29 | 0.83 | 1.31 | 1.73 | 4247 |
| Increased Beam Short Midbody | 160 | 27.42 | 5.85 | 1.21 | 1.55 | 1.90 | 3695 |
| +20% | 176 | 30.03 | 5.85 | 1.32 | 1.71 | 2.10 | 4433 |
| -20% | 143 | 24.52 | 5.85 | 1.08 | 1.38 | 1.69 | 2955 |
| Increased Beam Base Midbody | 206 | 27.42 | 7.52 | 1.24 | 1.66 | 2.06 | 4949 |
| +20% | 226 | 30.03 | 7.52 | 1.36 | 1.83 | 2.27 | 5938 |
| -20% | 184 | 24.52 | 7.52 | 1.10 | 1.48 | 1.82 | 3958 |
| Decreased Beam Short Midbody | 137 | 18.3 | 7.51 | 0.56 | 0.78 | 0.96 | 2044 |
| +20% | 151 | 20.04 | 7.51 | 0.62 | 0.86 | 1.07 | 2452 |
| -20% | 123 | 16.37 | 7.51 | 0.50 | 0.69 | 0.85 | 1635 |
| Decreased Beam Intermediate Midbody | 165 | 18.3 | 9.01 | 0.68 | 0.88 | 1.08 | 2544 |
| +20% | 181 | 20.04 | 9.01 | 0.75 | 0.97 | 1.19 | 3052 |
| -20% | 147 | 16.37 | 9.01 | 0.61 | 0.78 | 0.95 | 1035 |
| Decreased Beam Base Midbody | 206 | 18.3 | 11.27 | 0.86 | 1.00 | 1.20 | 3299 |
| +20% | 226 | 20.04 | 11.27 | 0.94 | 1.10 | 1.33 | 3958 |
| -20% | 184 | 16.37 | 11.27 | 0.76 | 0.89 | 1.06 | 2639 |

FIGURE 3.14

SHIP RESISTANCE vs. L/B RATIO

AT 1.0 m/sec

INCREASED WATERPLANE BY 20%




Ice Thickness = 0.9 m

Ice Strength = 500 kPa

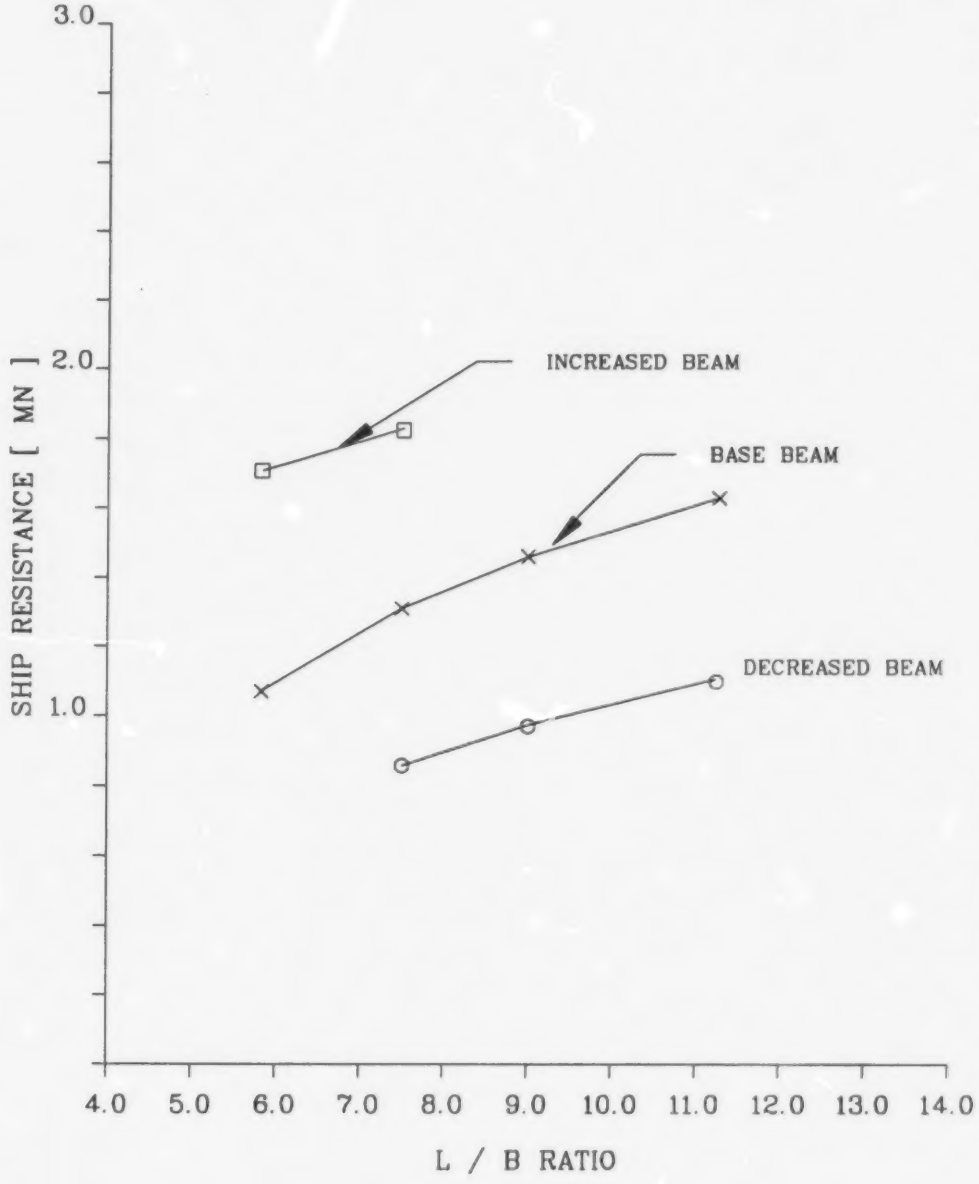
Friction Coefficient = 0.06

FIGURE 3.15

SHIP RESISTANCE vs. L/B RATIO

AT 2 m/sec

INCREASED WATERPLANE AREA BY 20%




Ice Thickness = 0.9 m

Ice Strength = 500 kPa

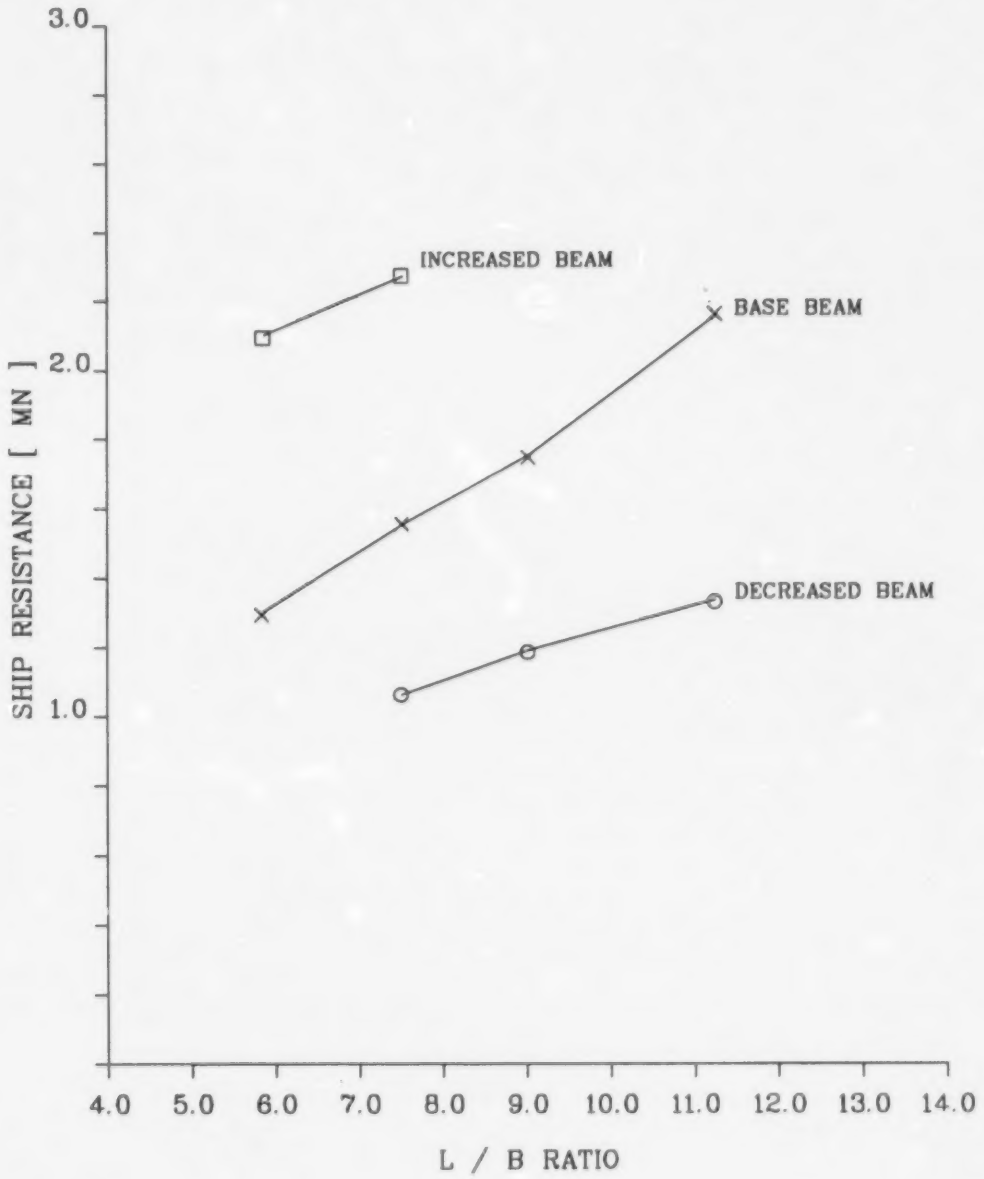
Friction Coefficient = 0.06

FIGURE 3.16

SHIP RESISTANCE vs. L/B RATIO

AT 3.0 m/sec

INCREASED WATERPLANE AREA BY 20%




Ice Thickness = 0.9 m

Ice Strength = 500 kPa

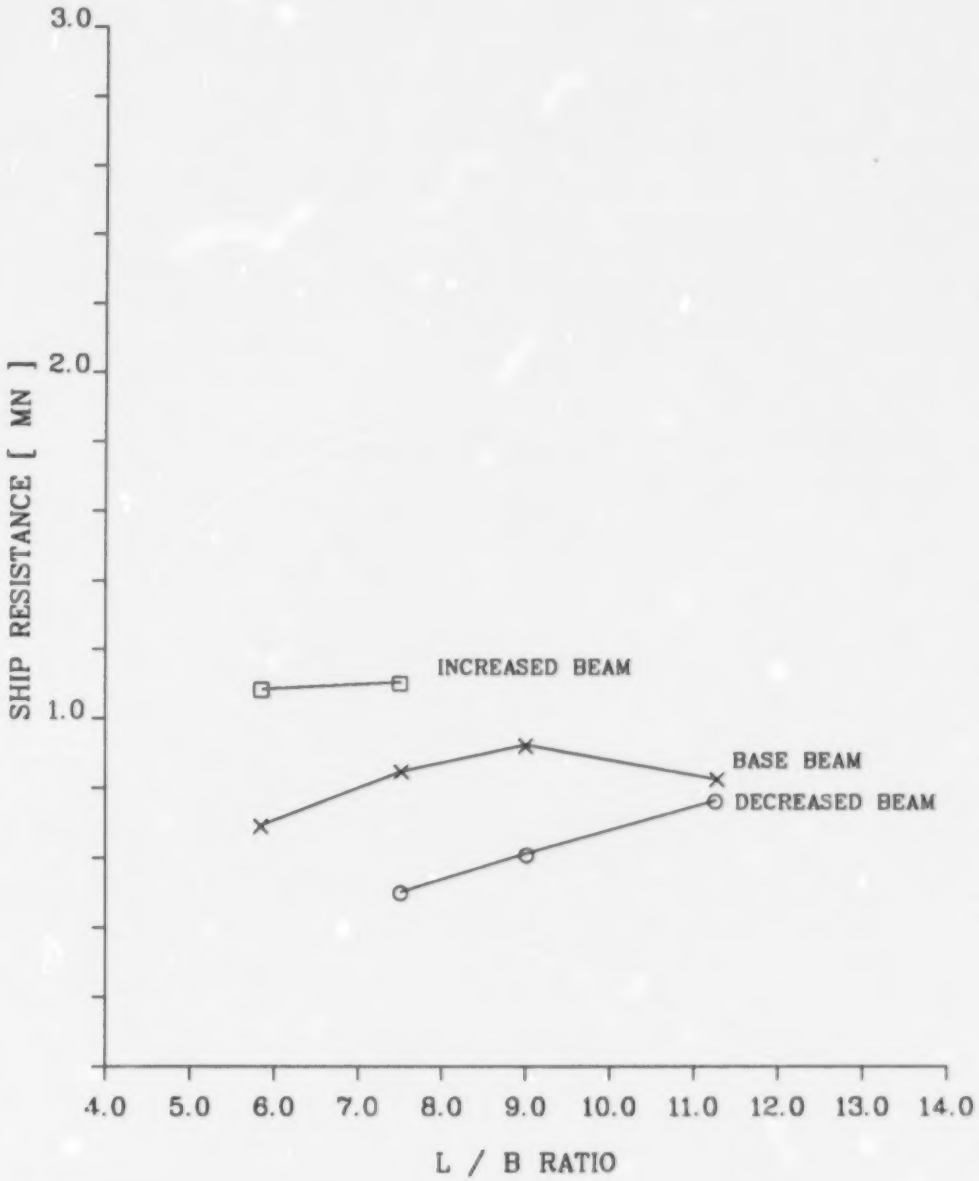
Friction Coefficient = 0.06

FIGURE 3.17

SHIP RESISTANCE vs. L/B RATIO

AT 1.0 m/sec

DECREASED WATERPLANE AREA BY 20%




Ice Thickness = 0.9 m

Ice Strength = 500 kPa

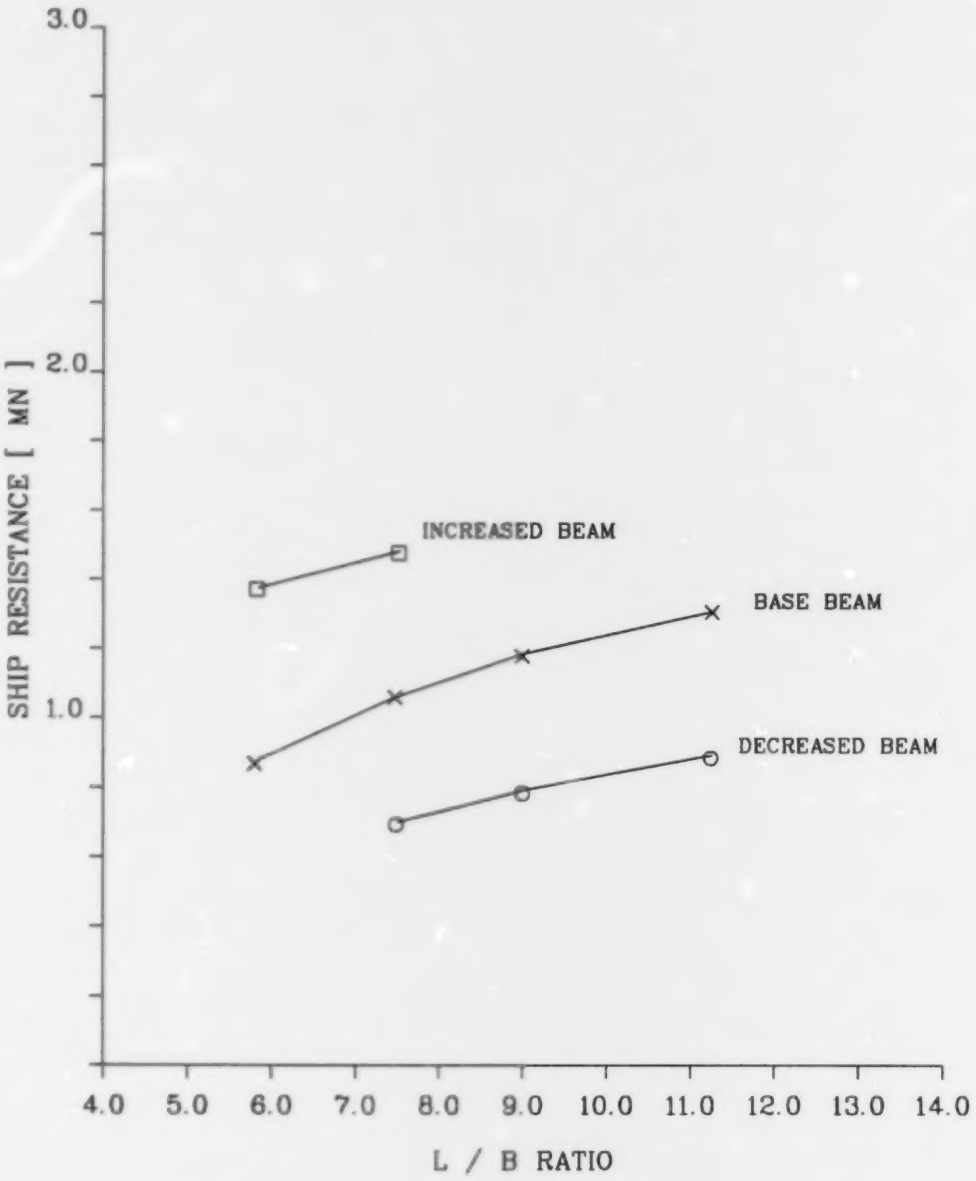
Friction Coefficient = 0.06

FIGURE 3.18

SHIP RESISTANCE vs. L/B RATIO

AT 2 m/sec

DECREASED WATERPLANE BY 20%



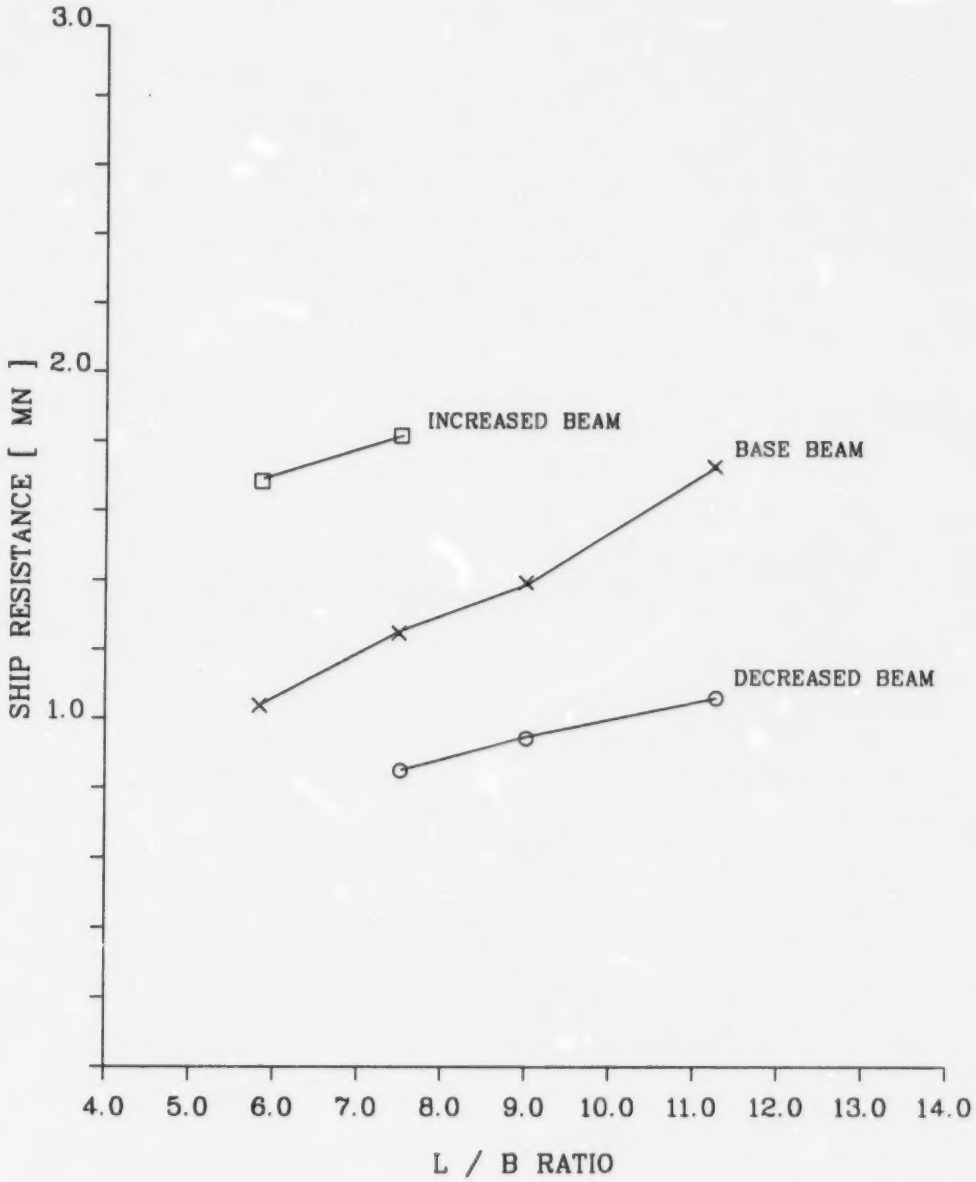

Ice Thickness = 0.9 m
Ice Strength = 500 kPa
Friction Coefficient = 0.06

FIGURE 3.19

SHIP RESISTANCE vs. L/B RATIO

AT 3.0 m/sec

DECREASED WATERPLANE AREA BY 20%




Ice Thickness = 0.9 m

Ice Strength = 500 kPa

Friction Coefficient = 0.06

# 4.0 CONCLUSIONS

The model tests described in the above report have contributed significantly to our understanding of the physical model testing of icebreaking ships. However, as with any research work it has also raised a number of issues which may significantly impact some of the assumptions that have been used in the past.

The conclusions of the report may be summarised as follows;

a) The influence of length on the total resistance has been shown to be small. This result confirms work completed as part of the FRICTION and MIDBODY test programs. In the FRICTION test program it was found that the model resistance did not significantly increase when the midbody friction coefficient was increased and in the MIDBODY test program the resistance was not found to increase significantly by adding midbody sections to the model of the existing ARCTIC. This result has now been extended to a range of different beams in this program.

b) The Ship Resistance vs Beam relationships for each model demonstrated a consistent trend between length and beam for the series of models tested. The results of the tests permitted lines of constant length to be drawn through curves of Ship Resistance vs Beam. This will permit an improved understanding of how ice performance may be optimised to achieve the best combination of ship length and breadth.

c) The model test results were corrected to the same beam and plotted as Ship Resistance vs Ship Length. The resultant curves illustrated a low dependence of length at low speed which increased with higher speeds. The difference between these curves was considered to be due to the different bow forms resulting from the parametric scaling of each model.

d) The model test results were plotted as Ship Resistance vs L/B ratio based on scaling each model configuration to a constant waterplane area. The results of this analysis illustrated that, since the length has a lower influence on resistance than the beam, the longer hulls tend to have lower resistances. An optimum length or L/B ratio was not found.

e) The results of the BEAM test program were compared with a second hull form identified as the NORDIC. The NORDIC has a similar bow form to the ARCTIC and an intermediate L/B ratio, however the analysis resulted in significantly different resistances. The primary cause of the difference was found to be the speed component which was significantly higher with the ARCTIC than with the NORDIC. Further analysis of the resistance was not possible within the scope of this project although the differences were partly attributed to the midbody flare and waterline knuckle on the NORDIC.

f) The detailed analysis of the model test results highlighted the need to define the model ice in more detail. In particular the current practice of randomly mixing the test speeds and locations in the ice tank is not recommended. This is done to average the influence of deviations along the ice tank length which are then considered to be lost in the regression analysis. The BEAM test program did not adopt this approach and was able to identify at least two cases of significant ice sheet deviations, not represented by the manual ice strength measurements, and that would have significantly influenced the results had they not been identified.

g) The results of the BEAM, FRICTION and MIDBODY test programs resulted in consistent data sets after corrections for thickness, strength and friction. This result tends to indicate that the "stochastic" approach to model testing that assumes there is a fundamental and significant deviation in test results due the nature of the tests is not correct. The major cause of model test deviation is considered to be the lack of correctly measuring the mechanical properties of the model ice.

h) The results of the model tests were analyzed with a procedure, frequently used at the IMD, based on a nondimensional analysis of the resistance developed by Dr. B. Colbourne. Although the analysis was generally found to be of value there are considered to be areas were the nondimensional forms could be improved.

## 5.0 RECOMMENDATIONS

The recommendations from this report may be summarised as follows:

a) There are a number of different procedures to analyze the results from ice tanks. Although the non-dimensional analysis, currently adopted by some of the scientists at the IMD, has benefits due to its regression approach, there are a number of other methods and it is considered that a review and analysis of the test procedures and analysis would permit tank users to more consistently evaluate the results from ice tank tests. The last time such an analysis was undertaken was in 1982, by Melville Shipping Ltd, and included three ice tanks.

b) The definition of model ice mechanical properties must be improved through a standard procedure that may be used for all model tests. This work is currently in the final stages of development with the INDEXER, a device invented by Melville and developed with the assistance of IMD and the Transportation Development Centre. The INDEXER should be adopted as a standard measuring device for all model tests in ice.

c) The continuing development of relationships between hull form and resistance should be continued with a focus on the components of resistance, the procedures used to measure them and the subsequent scaling relationships between model and full scale data. The work should include a better definition of how model resistance is influenced by ice strength, thickness and scale.

d) One major influence on scale relationships and the breaking component is considered to be the size and orientation of the ice cusping occurring at model scale. It is recommended that the influence on cusp size, model speed, ice strength and thickness is measured and compared with full scale data that could be obtained from the ARCTIC.

e) The MIDBODY program is the third in a series of model tests which have provided a consistent set of data for the ship designer. The next logical step in this process is considered to be an investigation of the influence of longitudinal radius of gyration on the model resistance. The MIDBODY and BEAM variation tests have permitted an understanding of two of the "size" variables with respect to performance, beam and length. The third important variable is considered to be the influence of the displacement of the model. This is manifest in the response of the model to the icebreaking process, which is controlled by the longitudinal radii of gyration. It is proposed that a series of tests are conducted with the ARCTIC and one other model to investigate the influence of this variable on resistance. The model would first be tested fully constrained and then with decreasing levels of longitudinal radii of gyration. The results could be used in conjunction with the existing data base of model

test information on the ARCTIC to evaluate the influence of model inertia on resistance.

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# APPENDIX A

# MODEL TEST DATA FROM THE MIDBODY, BEAM AND FRICTION TEST PROGRAMS

## A.1 Model Test Data

The raw data collected from the model tests are presented in tables A.1 and A.2. The tables also present the detailed calculation of the non-dimensional clearing and breaking coefficients. The following notes define each column;

Table A.1

a) Column 1 Description of the model; The model description is slightly different for each test program but is consistent in form. The BEAM project has a prefix of "MB" (Melville Bow), followed by the ice sheet number. The description then defines the beam as the original width "O", the increased beam "I" and the decreased beam "D". The description then defines the midbody length as the original midbody "O", the short midbody "S", or the long midbody "L". The last item in the description is the target ice thickness. Therefore, for example, the notation "MB03/0/L/30" represents the Beam test series, ice sheet #3, the model has the original beam, long midbody and was tested in 30 mm ice. The MIDBODY and FRICTION test series notation first defines the friction coefficient and bow form, then the friction coefficient of the midbody and its length with respect to the base midbody length, the "S" designates the stern and the last numbers define the target ice thickness. Therefore, for example, "0.06MB/0.06PB1.7/S/30" designates the Melville bow with a 0.06 friction coefficient, the long (1.7) midbody with a friction coefficient of 0.06, the stern and 30 mm ice thickness.

b) Column 2 Model speed

c) Column 3 Measured Ice thickness.

d) Column 4 Measured Ice flexural strength.

e) Column 5 Measured Ice density

f) Column 6 Measured total resistance with no corrections

g) Column 7 Friction correction. This correction factor is based on the results of previous model test programs and is a speed dependant function. The target friction coefficient is 0.06.

h) Column 8 Corrected total resistance.

i) Column 9 Calculated Clearing resistance. The clearing resistance is calculated from table A.2 using the calculated clearing coefficient and index for each model. These are presented in table A.3.

For Example;

Calculated Clearing Resistance = $AC*(\rho BhV^2)*((V/(gh)^{1/4}))^{n2}$

j) Column 10 Frictional resistance. The frictional resistance is calculated as a function of the Reynolds number and model length based on the ITTC line.

k) Column 11 Breaking resistance. The corrected total resistance, column 8, minus the calculated clearing resistance, column 9, and the frictional resistance, column 10.

l) Column 12 Non-Dimensional Breaking coefficient. Calculated with the algorithm; $R_b / (\rho BhV^2)$

m) Column 13 Ice Strength Number.
Calculated with the algorithm; $(V/(\sigma/\rho)^{1/4})$

n) Column 14 Calculated Breaking Resistance. The breaking resistance calculated from the coefficient and index for each model. These are presented in table A.3.

For example;

Calculated Breaking Resistance = $AB*(\rho BhV^2)*((V/(\sigma/\rho)^{1/4}))^{n1}$

o) Column 15 Calculated Total Resistance. The calculated breaking resistance, column 14, plus the calculated clearing resistance, column 9, plus the frictional resistance, column 10.

Table A.2

| | | |
|---|---|---|
| a) | Column 1 | Same as table A.1 |
| b) | Column 2 | Model speed. |
| c) | Column 3 | Measured Ice thickness. |
| d) | Column 4 | Estimated Ice flexural strength during presawn tests. |
| e) | Column 5 | Estimated Ice density during presawn tests |
| f) | Column 6 | Measured resistance during presawn test with no corrections |
| g) | Column 7 | Friction correction factor. |
| h) | Column 8 | Corrected presawn resistance. |
| i) | Column 9 | Frictional resistance. The frictional resistance is calculated as a function of the Reynolds number and model length and ITTC line. |
| k) | Column 10 | Total Clearing resistance. The corrected presawn resistance, column 8, minus the frictional resistance, column 9. |
| l) | Column 11 | Non-Dimensional Clearing Coefficient. Defined as; $R_c / (\rho B h V^2)$ |
| m) | Column 12 | Thickness Froude Number. Defined as; $V/(gh)^{1/4}$ |
| n) | Column 14 | Model Friction coefficient. |

Notes:

- The Presawn Resistance, column 8 of table A.2, is the corrected measured resistance. The Clearing Resistance, column 9 of table A.1, is the calculated resistance based on the coefficients AC and n2 developed from the regression analysis of the Non-dimensional Clearing coefficient and Thickness Froude Number, at the model test speed.

- The Clearing and Breaking resistances presented and calculated from tables A1, A2 and A3 will be different from those resistances presented and calculated in the Model Test Report, Appendix B, tables B3.2.1 and B3.2.2 for two reasons:

1. The Model Test Report tables B3.2.1 and B3.2.2 do not include a correction for friction, shown as column 7 in tables A1 and A2.

2. The data base used for the regression equations in tables B3.2.1 and B3.2.2 do not include the FRICTION and MIDBODY test results and will therefore result in different coefficients and different calculated resistances.

- For definition of variables see the nomenclature in the model test report pages Biii to Bv.

TABLE A.1

BEAM , FRICTION AND MEBODY TEST RESULTS

CALCULATION OF NONDIMENSIONAL BREAKING COEFFICIENT

| COLUMN # | 2 SPEED (m/s) | 3 ICE THICK (mm) | 4 FLEXURAL STRENGTH (kPa) | 5 DENSITY (kg/m^3) | 6 MEAS RES | 7 FRICT CORR | 8 CORR RESIST. (N) | 9 CLEARING RESIST. (N) | 10 FRICTIONAL RESISTANCE (N) | 11 BREAKING RESIST. (N) | 12 NON-DIM BREAKING COEFF. | 13 ICE STRENGTH # | 14 FRICT. COEFF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MB01/O/O/30 | 0.166 | 29.50 | 21.00 | 944.91 | 59.00 | 0.79 | 46.84 | 11.43 | 0.57 | 34.85 | 59.54 | 1.1135 | 0.10 |
| MB01/O/O/30 | 0.307 | 29.60 | 24.00 | 944.36 | 73.00 | 0.80 | 58.58 | 15.25 | 1.71 | 41.61 | 20.73 | 1.9256 | 0.10 |
| MB01/O/O/30 | 0.448 | 30.00 | 16.67 | 945.61 | 71.56 | 0.81 | 58.05 | 18.35 | 3.37 | 36.31 | 8.37 | 3.3743 | 0.10 |
| MB01/O/O/30 | 0.578 | 29.30 | 22.00 | 944.78 | 94.00 | 0.82 | 76.96 | 20.42 | 5.33 | 51.21 | 7.27 | 3.7878 | 0.10 |
| MB05/O/O/40 | 0.190 | 39.30 | 20.00 | 941.00 | 68.00 | 0.84 | 56.85 | 20.27 | 0.73 | 35.85 | 35.24 | 1.3033 | 0.10 |
| MB05/O/O/40 | 0.330 | 39.80 | 22.00 | 940.37 | 93.00 | 0.79 | 73.19 | 26.01 | 1.95 | 45.23 | 14.56 | 2.1575 | 0.10 |
| MB05/O/O/40 | 0.471 | 39.20 | 17.00 | 941.68 | 101.00 | 0.74 | 74.50 | 30.94 | 3.69 | 39.88 | 6.39 | 3.5055 | 0.10 |
| MB05/O/O/40 | 0.601 | 40.00 | 16.67 | 941.41 | 122.80 | 0.69 | 85.00 | 34.05 | 5.72 | 45.23 | 4.56 | 4.5164 | 0.10 |
| 0.06MB/.06PB/S/30 | 0.188 | 30.00 | 19.00 | 936.72 | | | 76.53 | 30.18 | 0.71 | 45.63 | 36.18 | 1.3200 | 0.06 |
| 0.06MB/.06PB/S/50 | 0.329 | 50.00 | 19.00 | 936.72 | | | 92.90 | 39.68 | 1.94 | 50.88 | 13.17 | 2.3101 | 0.06 |
| 0.06MB/.06PB/S/50 | 0.470 | 50.00 | 19.00 | 936.72 | | | 107.64 | 47.25 | 3.67 | 56.72 | 7.19 | 3.3001 | 0.06 |
| 0.06MB/.06PB/S/50 | 0.600 | 50.00 | 19.00 | 936.72 | | | 119.57 | 53.36 | 5.70 | 60.63 | 4.72 | 4.2129 | 0.06 |
| 0.06MB/.06PB/S/40 | 0.188 | 40.00 | 19.00 | 940.92 | | | 60.93 | 20.49 | 0.71 | 39.73 | 39.19 | 1.3230 | 0.06 |
| 0.06MB/.06PB/S/40 | 0.329 | 40.00 | 19.00 | 940.92 | | | 71.18 | 26.94 | 1.94 | 42.30 | 13.63 | 2.3152 | 0.06 |
| 0.06MB/.06PB/S/40 | 0.470 | 40.00 | 19.00 | 940.92 | | | 80.43 | 32.08 | 3.67 | 44.68 | 7.05 | 3.3075 | 0.06 |
| 0.06MB/.06PB/S/40 | 0.600 | 40.00 | 19.00 | 940.92 | | | 90.33 | 36.15 | 5.70 | 48.49 | 4.70 | 4.2223 | 0.06 |
| 0.06MB/.06PB/S/30 | 0.188 | 30.00 | 19.00 | 945.12 | | | 60.54 | 12.42 | 0.71 | 27.40 | 35.89 | 1.3250 | 0.06 |
| 0.06MB/.06PB/S/30 | 0.329 | 30.00 | 19.00 | 945.12 | | | 69.69 | 16.33 | 1.94 | 31.22 | 13.35 | 2.3204 | 0.06 |
| 0.06MB/.06PB/S/30 | 0.470 | 30.00 | 19.00 | 945.12 | | | 77.75 | 19.45 | 3.67 | 34.63 | 7.26 | 3.3149 | 0.06 |
| 0.06MB/.06PB/S/30 | 0.600 | 30.00 | 19.00 | 945.12 | | | 83.53 | 21.91 | 5.70 | 35.71 | 4.59 | 4.2317 | 0.06 |
| MB02/D/O/30 | 0.166 | 29.50 | 24.00 | 944.28 | 56.60 | 0.74 | 41.90 | 8.75 | 0.52 | 32.53 | 69.68 | 1.0412 | 0.12 |
| MB02/D/O/30 | 0.307 | 29.70 | 24.00 | 944.20 | 61.40 | 0.75 | 46.06 | 15.19 | 1.55 | 29.32 | 18.19 | 1.9256 | 0.12 |
| MB02/D/O/30 | 0.448 | 29.60 | 24.00 | 944.24 | 58.56 | 0.76 | 44.61 | 20.91 | 3.06 | 20.65 | 6.03 | 2.8100 | 0.12 |
| MB02/D/O/30 | 0.578 | 29.10 | 28.00 | 943.61 | 77.80 | 0.77 | 60.10 | 25.93 | 4.83 | 29.34 | 5.24 | 3.3554 | 0.12 |
| MB03/D/I/30 | 0.190 | 28.90 | 30.00 | 945.37 | 59.20 | 0.74 | 29.03 | 7.70 | 0.53 | 20.81 | 34.58 | 1.3063 | 0.12 |
| MB03/D/I/30 | 0.331 | 29.20 | 26.00 | 943.99 | 46.50 | 0.75 | 34.98 | 12.18 | 1.41 | 21.38 | 11.61 | 1.9945 | 0.12 |
| MB03/D/I/30 | 0.472 | 29.20 | 26.00 | 943.99 | 56.60 | 0.76 | 43.23 | 16.41 | 2.67 | 24.15 | 6.45 | 2.8441 | 0.12 |
| MB03/D/I/30 | 0.601 | 30.00 | 27.00 | 943.44 | 69.73 | 0.77 | 54.00 | 18.68 | 4.11 | 31.20 | 5.00 | 3.5526 | 0.12 |
| MB04/D/S/30 | 0.190 | 29.90 | 25.00 | 943.90 | 35.70 | 0.74 | 26.44 | 9.13 | 0.43 | 16.87 | 27.15 | 1.1675 | 0.12 |
| MB04/D/S/30 | 0.331 | 29.70 | 30.00 | 942.94 | 45.50 | 0.75 | 34.22 | 12.58 | 1.16 | 20.69 | 11.05 | 1.8557 | 0.12 |
| MB04/D/S/30 | 0.472 | 30.50 | 27.00 | 943.23 | 55.10 | 0.76 | 42.08 | 15.96 | 2.18 | 23.94 | 6.12 | 2.7898 | 0.12 |
| MB04/D/S/30 | 0.601 | 29.80 | 29.00 | 943.10 | 60.50 | 0.77 | 46.85 | 17.49 | 3.36 | 25.99 | 4.20 | 3.4273 | 0.12 |
| MB06/O/L/30 | 0.190 | 29.10 | 24.00 | 944.45 | 50.00 | 0.80 | 39.77 | 14.60 | 0.90 | 24.27 | 32.10 | 1.1919 | 0.06 |
| MB06/O/L/30 | 0.331 | 29.30 | 25.00 | 944.15 | 71.00 | 0.80 | 57.07 | 20.48 | 2.44 | 34.16 | 14.79 | 2.0341 | 0.06 |
| MB06/O/L/30 | 0.472 | 28.80 | 25.00 | 944.36 | 90.16 | 0.81 | 73.24 | 25.61 | 4.63 | 43.01 | 9.32 | 2.9010 | 0.06 |
| MB06/O/L/30 | 0.601 | 28.20 | 29.00 | 943.78 | 104.00 | 0.82 | 85.29 | 28.12 | 7.14 | 50.03 | 6.83 | 3.4285 | 0.06 |
| .06MB/.06PB1.7/S/30 | 0.189 | 30.00 | 19.00 | 945.12 | | | 37.22 | 15.28 | 0.90 | 21.04 | 27.26 | 1.3330 | 0.06 |
| .06MB/.06PB1.7/S/30 | 0.329 | 30.00 | 19.00 | 945.12 | | | 54.93 | 21.68 | 2.41 | 30.83 | 13.18 | 2.3204 | 0.06 |
| .06MB/.06PB1.7/S/30 | 0.470 | 30.00 | 19.00 | 945.12 | | | 68.49 | 27.15 | 4.56 | 36.76 | 7.70 | 3.3149 | 0.06 |
| .06MB/.06PB1.7/S/30 | 0.600 | 30.00 | 19.00 | 945.12 | | | 81.666 | 31.66 | 7.12 | 42.88 | 5.51 | 4.2317 | 0.06 |
| MB07/I/O/30 | 0.190 | 29.90 | 24.00 | 944.11 | 61.00 | 0.94 | 57.35 | 20.78 | 0.80 | 35.77 | 38.40 | 1.1917 | 0.07 |
| MB07/I/O/30 | 0.331 | 30.40 | 24.00 | 943.90 | 71.00 | 0.94 | 67.05 | 31.73 | 2.15 | 33.14 | 11.53 | 2.0758 | 0.07 |
| MB07/I/O/30 | 0.472 | 30.20 | 22.00 | 944.41 | 87.00 | 0.95 | 82.67 | 41.16 | 4.07 | 37.24 | 6.41 | 3.0925 | 0.07 |
| MB07/I/O/30 | 0.601 | 29.90 | 22.00 | 944.53 | 90.00 | 0.95 | 85.63 | 48.34 | 6.29 | 31.01 | 3.33 | 3.9380 | 0.07 |
| MB08/I/S/30 | 0.190 | 30.00 | 24.00 | 944.07 | 60.50 | 0.94 | 56.88 | 21.05 | 0.62 | 35.22 | 37.68 | 1.1917 | 0.07 |
| MB08/I/S/30 | 0.331 | 30.20 | 23.00 | 944.20 | 65.10 | 0.94 | 61.46 | 31.93 | 1.66 | 27.86 | 9.76 | 2.1208 | 0.07 |
| MB08/I/S/30 | 0.472 | 30.00 | 24.00 | 944.07 | 81.60 | 0.95 | 77.35 | 42.22 | 3.13 | 32.00 | 5.55 | 2.9603 | 0.07 |
| MB08/I/S/30 | 0.601 | 29.70 | 24.00 | 944.20 | 85.60 | 0.95 | 81.44 | 48.88 | 4.84 | 27.73 | 3.00 | 3.7696 | 0.07 |
| .06MB/S/30 | 0.19 | 30.00 | 19.00 | 945.12 | | | 33.85 | 15.73 | 0.45 | 17.67 | 19.39 | 1.3259 | 0.06 |
| .06MB/S/30 | 0.33 | 30.00 | 19.00 | 945.12 | | | 38.37 | 22.23 | 1.22 | 14.91 | 5.32 | 2.3204 | 0.06 |
| .06MB/S/30 | 0.47 | 30.00 | 19.00 | 945.12 | | | 44.51 | 27.73 | 2.31 | 14.47 | 2.53 | 3.3149 | 0.06 |
| .06MB/S/30 | 0.60 | 30.00 | 19.00 | 945.12 | | | 49.38 | 32.25 | 3.58 | 13.56 | 1.45 | 4.2317 | 0.06 |
| .06MB/.06PB.5/S/30 | 0.19 | 30.00 | 19.00 | 945.12 | | | 37.67 | 9.53 | 0.60 | 27.54 | 35.68 | 1.3330 | 0.06 |
| .06MB/.06PB.5/S/30 | 0.33 | 30.00 | 19.00 | 945.12 | | | 50.40 | 14.32 | 1.61 | 34.47 | 14.74 | 2.3204 | 0.06 |
| .06MB/.06PB.5/S/30 | 0.47 | 30.00 | 19.00 | 945.12 | | | 49.95 | 18.60 | 3.05 | 28.29 | 5.93 | 3.3149 | 0.06 |
| .06MB/.06PB.5/S/30 | 0.60 | 30.00 | 19.00 | 945.12 | | | 58.30 | 23.25 | 4.73 | 31.32 | 4.03 | 4.2317 | 0.06 |

TABLE A.2

BEAM , FRICTION AND MIDBODY TEST RESULTS

CALCULATION OF NONDIMENSIONAL CLEARING COEFFICIENT

| COLUMN # / MODEL TEST # | 2 SPEED (m/s) | 3 ICE THICK (mm) | 4 ICE STRENGTH (kPa) | 5 DENSITY (kg/m^3) | 6 P.SAWN RESIST. | 7 FRICT CORR | 8 CORR RESIST. (N) | 9 FRICTIONAL RES. (N) | 10 NET RES. (N) | 11 NON-DIM CLEARING COEFF | 12 THICKNESS FROUDE # |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MB01/O/O/50 | 0.166 | 29.60 | 16.30 | 945.86 | 19.00 | 0.76 | 14.41 | 0.57 | 13.84 | 23.54 | 0.31 |
| MB01/O/O/50 | 0.307 | 29.40 | 16.30 | 945.94 | 22.00 | 0.77 | 16.94 | 1.71 | 15.23 | 7.63 | 0.57 |
| MB01/O/O/50 | 0.448 | 29.40 | 16.30 | 945.94 | 33.00 | 0.78 | 25.02 | 3.37 | 21.65 | 5.09 | 0.83 |
| MB01/O/O/50 | 0.578 | 29.10 | 16.30 | 946.07 | 38.00 | 0.79 | 30.11 | 5.33 | 24.79 | 3.54 | 1.08 |
| MB05/O/O/40 | 0.190 | 39.60 | 13.00 | 942.35 | 35.00 | 0.81 | 28.26 | 0.73 | 27.53 | 26.82 | 0.30 |
| MB05/O/O/40 | 0.331 | 39.10 | 13.00 | 942.56 | 41.00 | 0.76 | 31.05 | 1.95 | 29.10 | 9.46 | 0.53 |
| MB05/O/O/40 | 0.472 | 39.10 | 13.00 | 942.56 | 49.00 | 0.71 | 34.65 | 3.69 | 30.96 | 4.95 | 0.76 |
| MB05/O/O/40 | 0.601 | 38.60 | 13.00 | 942.77 | 59.00 | 0.66 | 39.01 | 5.72 | 33.29 | 3.32 | 0.98 |
| 0.06MB/.06PB/5/50 | 0.188 | 30.00 | 19.00 | 936.72 | | | 29.74 | 0.71 | 29.03 | 23.01 | 0.27 |
| 0.06MB/.06PB/5/50 | 0.329 | 30.00 | 19.00 | 936.72 | | | 42.27 | 1.94 | 40.34 | 10.44 | 0.47 |
| 0.06MB/.06PB/5/50 | 0.470 | 30.00 | 19.00 | 936.72 | | | 46.72 | 3.67 | 43.05 | 5.46 | 0.67 |
| 0.06MB/.06PB/5/50 | 0.600 | 30.00 | 19.00 | 936.72 | | | 52.61 | 5.70 | 46.91 | 3.65 | 0.86 |
| 0.06MB/0.06PB/5/40 | 0.188 | 40.00 | 19.00 | 940.92 | | | 17.41 | 0.71 | 16.69 | 16.47 | 0.30 |
| 0.06MB/0.06PB/5/40 | 0.329 | 40.00 | 19.00 | 940.92 | | | 25.10 | 1.94 | 23.16 | 7.46 | 0.53 |
| 0.06MB/0.06PB/5/40 | 0.470 | 40.00 | 19.00 | 940.93 | | | 33.19 | 3.67 | 29.51 | 4.66 | 0.75 |
| 0.06MB/0.06PB/5/40 | 0.600 | 40.00 | 19.00 | 940.92 | | | 38.84 | 5.70 | 33.14 | 3.21 | 0.96 |
| 0.06MB/.06PB/5/50 | 0.188 | 30.00 | 19.00 | 945.13 | | | 11.77 | 0.71 | 11.06 | 14.48 | 0.35 |
| 0.06MB/.06PB/5/50 | 0.329 | 30.00 | 19.00 | 945.13 | | | 16.08 | 1.94 | 14.15 | 6.05 | 0.61 |
| 0.06MB/.06PB/5/50 | 0.470 | 30.00 | 19.00 | 945.13 | | | 22.87 | 3.67 | 19.19 | 4.02 | 0.87 |
| 0.06MB/.06PB/5/50 | 0.600 | 30.00 | 19.00 | 945.13 | | | 29.81 | 5.70 | 24.12 | 3.10 | 1.11 |
| MB02/O/O/50 | 0.166 | 29.40 | 13.70 | 946.49 | 13.50 | 0.74 | 9.97 | 0.52 | 9.45 | 20.21 | 0.31 |
| MB02/O/O/30 | 0.307 | 30.00 | 13.70 | 946.23 | 19.98 | 0.75 | 14.99 | 1.55 | 13.44 | 8.23 | 0.57 |
| MB02/O/O/30 | 0.448 | 30.00 | 13.70 | 946.23 | 28.66 | 0.76 | 22.58 | 3.06 | 19.52 | 5.62 | 0.83 |
| MB02/O/O/50 | 0.578 | 30.00 | 13.70 | 946.23 | 43.89 | 0.77 | 33.90 | 4.83 | 29.07 | 5.02 | 1.07 |
| MB03/O/I/50 | 0.190 | 27.80 | 10.60 | 947.81 | 12.00 | 0.74 | 8.89 | 0.53 | 8.36 | 14.41 | 0.36 |
| MB03/O/I/50 | 0.331 | 28.60 | 10.60 | 947.47 | 16.00 | 0.75 | 12.05 | 1.41 | 10.62 | 5.86 | 0.63 |
| MB03/O/I/50 | 0.472 | 29.20 | 10.60 | 947.22 | 24.00 | 0.76 | 18.33 | 2.67 | 15.66 | 4.17 | 0.88 |
| MB03/O/I/50 | 0.601 | 28.30 | 10.60 | 947.60 | 33.00 | 0.77 | 24.78 | 4.11 | 20.66 | 3.50 | 1.14 |
| MB04/O/S/50 | 0.190 | 30.00 | 20.50 | 944.81 | 13.90 | 0.74 | 10.29 | 0.43 | 9.86 | 15.80 | 0.35 |
| MB04/O/S/50 | 0.331 | 29.60 | 20.50 | 944.97 | 16.10 | 0.75 | 12.11 | 1.16 | 10.95 | 5.86 | 0.61 |
| MB04/O/S/50 | 0.472 | 30.40 | 20.50 | 944.64 | 22.50 | 0.76 | 17.18 | 2.18 | 15.00 | 3.84 | 0.86 |
| MB04/O/S/50 | 0.601 | 29.50 | 20.50 | 945.02 | 29.50 | 0.77 | 22.84 | 3.36 | 19.48 | 3.17 | 1.12 |
| MB06/O/L/50 | 0.190 | 29.10 | 11.90 | 946.99 | 23.00 | 0.76 | 17.49 | 0.90 | 16.59 | 21.88 | 0.36 |
| MB06/O/L/50 | 0.331 | 28.90 | 11.90 | 947.07 | 33.00 | 0.77 | 25.48 | 2.44 | 23.04 | 10.08 | 0.62 |
| MB06/O/L/50 | 0.472 | 28.90 | 11.90 | 947.07 | 40.00 | 0.78 | 31.35 | 4.62 | 26.73 | 5.75 | 0.89 |
| MB06/O/L/50 | 0.601 | 27.90 | 11.90 | 947.49 | 52.00 | 0.79 | 41.31 | 7.14 | 34.17 | 4.70 | 1.15 |
| .06MB/.06PB1.7/5/50 | 0.190 | 30.00 | 19.00 | 945.13 | | | 15.33 | 0.90 | 14.43 | 18.70 | 0.35 |
| .06MB/.06PB1.7/5/50 | 0.329 | 30.00 | 19.00 | 945.13 | | | 20.19 | 2.41 | 17.78 | 7.60 | 0.61 |
| .06MB/.06PB1.7/5/50 | 0.470 | 30.00 | 19.00 | 945.13 | | | 28.60 | 4.58 | 24.02 | 5.03 | 0.87 |
| .06MB/.06PB1.7/5/50 | 0.600 | 30.00 | 19.00 | 945.13 | | | 35.62 | 7.12 | 28.50 | 3.66 | 1.11 |
| MB07/I/O/50 | 0.190 | 29.70 | 17.30 | 945.60 | 23.00 | 0.94 | 21.62 | 0.80 | 20.82 | 22.47 | 0.35 |
| MB07/I/O/50 | 0.331 | 30.00 | 17.30 | 945.48 | 36.00 | 0.94 | 33.99 | 2.15 | 31.83 | 11.21 | 0.61 |
| MB07/I/O/50 | 0.472 | 30.00 | 17.30 | 945.48 | 47.00 | 0.95 | 44.55 | 4.07 | 40.48 | 7.01 | 0.87 |
| MB07/I/O/50 | 0.601 | 29.70 | 17.30 | 945.60 | 58.00 | 0.95 | 55.18 | 6.29 | 48.90 | 5.27 | 1.11 |
| MB08/I/S/50 | 0.190 | 29.70 | 11.10 | 946.91 | 23.50 | 0.94 | 22.09 | 0.62 | 21.47 | 23.14 | 0.35 |
| MB08/I/S/50 | 0.331 | 29.80 | 11.10 | 946.86 | 34.56 | 0.94 | 32.63 | 1.66 | 30.96 | 10.96 | 0.61 |
| MB08/I/S/50 | 0.472 | 30.10 | 11.10 | 946.74 | 47.00 | 0.95 | 44.55 | 3.13 | 41.42 | 7.14 | 0.87 |
| MB08/I/S/50 | 0.601 | 29.50 | 11.10 | 946.99 | 58.00 | 0.95 | 55.18 | 4.84 | 50.35 | 5.46 | 1.12 |
| .06MB/S/30 | 0.19 | 30.00 | 19.00 | 945.12 | | | 16.68 | 0.45 | 16.22 | 21.25 | 0.35 |
| .06MB/S/50 | 0.33 | 30.00 | 19.00 | 945.12 | | | 22.27 | 1.22 | 21.05 | 9.00 | 0.61 |
| .06MB/S/50 | 0.47 | 30.00 | 19.00 | 945.12 | | | 29.68 | 2.31 | 27.36 | 5.73 | 0.87 |
| .06MB/S/50 | 0.60 | 30.00 | 19.00 | 945.12 | | | 37.03 | 3.58 | 33.45 | 4.30 | 1.11 |
| .06MB/.06PB.5/S/50 | 0.19 | 30.00 | 19.00 | 945.12 | | | 9.93 | 0.60 | 9.32 | 12.08 | 0.35 |
| .06MB/.06PB.5/S/50 | 0.33 | 30.00 | 19.00 | 945.12 | | | 16.57 | 1.61 | 14.96 | 6.40 | 0.61 |
| .06MB/.06PB.5/S/50 | 0.47 | 30.00 | 19.00 | 945.12 | | | 21.57 | 3.05 | 18.51 | 3.88 | 0.87 |
| .06MB/.06PB.5/S/50 | 0.60 | 30.00 | 19.00 | 945.12 | | | 26.60 | 4.73 | 21.87 | 2.81 | 1.11 |

TABLE A.3
NONDIMENSIONAL COEFFICIENTS AND INDICES

| COLUMN # DESCRIPTION OF MODEL # | 2 MODEL BEAM [ m ] | 3 CLEARING INDEX n2 | 4 CLEARING COEFF. AC | 5 BREAKING INDEX n1 | 6 BREAKING COEFF. AB |
|---|---|---|---|---|---|
| MB01/O/O/30 0.06MB/0.06PB/S/40 0.06MB/.06PB/S/30 | 0.762 | (1.51) | 3.28 | (1.77) | 61.52 |
| MB02/D/O/30 | 0.610 | (1.15) | 4.82 | (2.30) | 76.83 |
| MB03/D/I/30 | 0.610 | (1.26) | 3.73 | (1.94) | 52.17 |
| MB04/D/S/30 | 0.610 | (1.41) | 3.33 | (1.71) | 34.13 |
| MB06/O/L/30 .06MB/.06PB1.7/S/30 | 0.762 | (1.37) | 4.67 | (1.41) | 41.05 |
| MB07/I/O/30 | 0.914 | (1.27) | 5.98 | (1.98) | 53.28 |
| MB08/I/S/30 | 0.914 | (1.26) | 6.09 | (2.16) | 53.71 |
| .06MB/S/30 | 0.762 | (1.38) | 3.25 | (1.22) | 35.59 |
| .06MB/.06PB.5/S/30 | 0.762 | (1.27) | 3.25 | (1.94) | 65.62 |

# APPENDIX B

# MODEL TEST REPORT

P89-02

# ICEBREAKER MIDBODY RESISTANCE BEAM VARIATION

## APPENDIX B

## MODEL TEST REPORT

for

**Transportation Development Centre**
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by

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March 1990

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## APPENDICES


B1.0 Hydrostatics and Hull Form Coefficients of Model and Full Scale Ship
B2.0 Friction Test Results
B3.0 Ice Breaking Model Test Results
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B4.0 Ice Sheet Data

# NOMENCLATURE

| SYMBOLS | UNITS | DESCRIPTION |
|---|---|---|
| AB | - | Coefficient for breaking component Regression equation |
| AC | - | Coefficient for clearing component Regression equation |
| B | m | Model beam |
| CFM | - | Frictional resistance coefficient for the model |
| F | N | Friction force measured during ice/hull friction experiments |
| FN | - | Froude number based on ships waterline length |
| g | $m/s^2$ | Gravitational constant |
| h | mm | Ice thickness |
| kL | m | Longitudinal radius of Gyration |
| kT | m | Transverse radius of Gyration |
| LWL | m | Load Water Line |
| m | m | Meters |
| N | N | Newtons |

## NOMENCLATURE CONTINUED

| SYMBOLS | UNITS | DESCRIPTION |
|---|---|---|
| NF | N | Normal force measured during ice/hull friction experiment |
| nl | - | Exponent for breaking component Regression equation |
| n2 | - | Exponent for clearing component Regression equation |
| RB | N | Breaking component of resistance |
| RC | N | Clearing component of resistance |
| RFW | N | Frictional resistance in water |
| RTW | N | Total resistance in water |
| RT | N | Total resistance in ice |
| s | s | Time in seconds |
| S | $m^2$ | Wetted area of hull |
| SO | - | Static offset from friction tests |
| TH | N | Propeller thrust |
| V | m/s | Model Speed |
| $\rho$ | $kg/m^3$ | Density of tank water |
| $\mu$ | - | Coefficient of friction |
| $\Delta$ | $m^3$ | Volume of displacement |

## NOMENCLATURE CONTINUED

| SYMBOLS | UNITS | DESCRIPTION |
|---|---|---|
| $\sigma_c$ | kPa | Compressive strength of ice |
| $\sigma_s$ | kPa | Shear strength of ice |
| $\sigma_f$ | kPa | Flexural strength of ice |

# 1. INTRODUCTION

This report describes a series of model tests using 1:30 scale models representing the existing 'MV ARCTIC' and two parameter beam variations of the same hull form 20 percent wider and 20 percent narrower. The test program also included a length variation analysis by removing/adding segments from/to each model. The objective of the tests was to investigate the influence of length and beam on icebreaking performance. The model tests were conducted at the Institute for Marine Dynamics (IMD) in St. John's, Newfoundland.

# 2. TEST FACILITY

## 2.1 General

The Institute for Marine Dynamics, in St. John's, Newfoundland was opened in November of 1985 (Jones 1985). The facility is part of the National Research Council of Canada and offers three main test facilities, an ice tank, a manoeuvring basin and a towing tank. An overall plan of the facility is shown in Figure 2.1.

Of particular interest to this test program is the ice tank.

## 2.2 Ice Tank

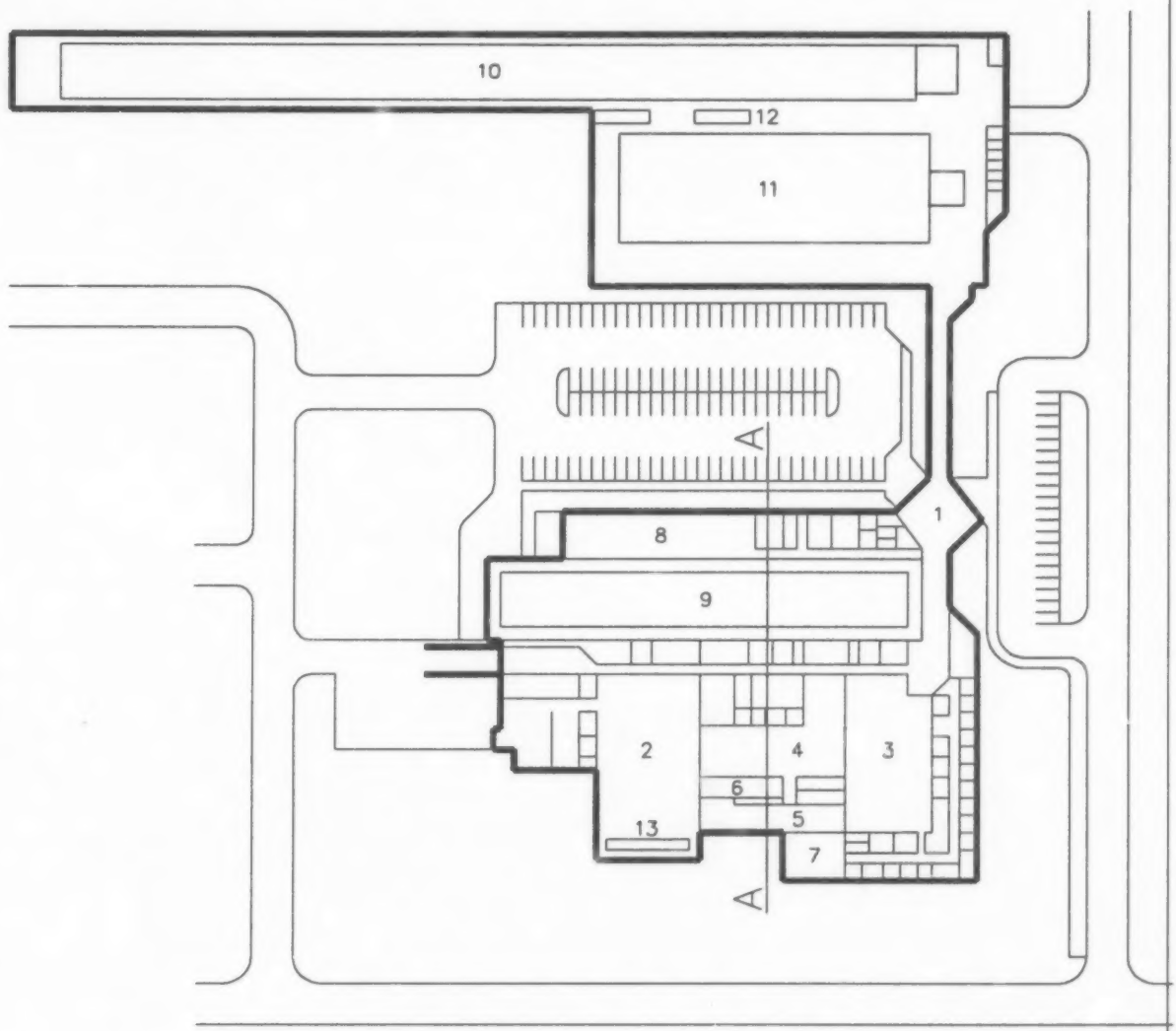
The ice tank is one of the largest refrigerated towing tanks in the world with a width of 12 m, a depth of 3 m and a usable ice sheet length of 76 m. A section through the tank is shown in Figure 2.2. In addition, a 15 m long setting-up area is located at one end of the towing tank and is separated from it by a thermal barrier gate. The opposite end of the tank has a sloped ramp leading into a melt pit which has an insulated cover to enable the next ice sheet to be grown while the remains of the previous one are melting.

The basin uses EG/AD/S ice developed by Dr. G. Timco of the National Research Council. The particular EG/AD/S dopant used during the test program was 0.39% ethylene glycol, 0.036% aliphatic detergent and 0.03% sugar.

The refrigeration system uses two-stage mechanical compression and water cooled condensers. The rejected heat is reclaimed for ice melting and tank wall perimeter heating, via embedded pipes fed with glycol, for ice sheet release. The ammonia refrigerant is delivered to 24 ceiling hung evaporators in the main tank plus two similar units in the setting up area. Compressor capacity, evaporating pressure and fan speed are computer controlled in order to obtain a uniform temperature distribution near the water surface. The objective is to provide a cold air supply over the upper part of the basin with heat transfer near the ice sheet/air interface by natural convection. The air temperature can be controlled from -30°C to +15°C and ice growth rates of 2.5 mm/hour have been obtained. A separate chiller system is used initially to cool the water.

FIGURE 2.1

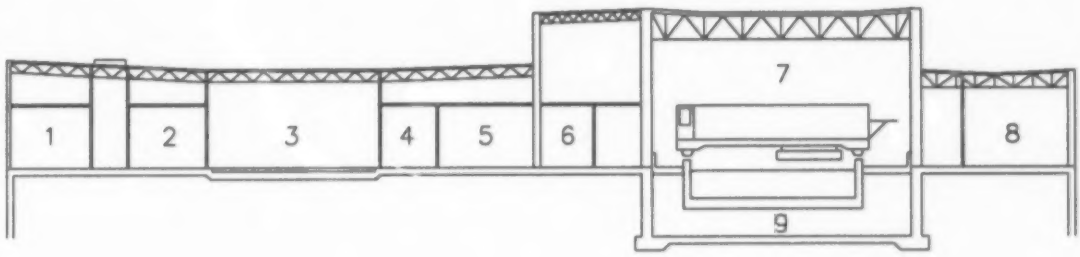
PLAN VIEW OF THE IMD FACILITY




1. Main Lobby
2. Model Making Shop
3. Model Preparation Shop
4. Machine Shop
5. Paint Shop
6. Fibreglass Shop
7. CISTI
8. Refrigeration Plant
9. Ice Tank
10. Towing Tank
11. Seakeeping Tank
12. Cavitation Tunnel
13. Milling Pit

FIGURE 2.2

SECTION THROUGH ICE TANK




Section A–A

1. Paint Shop
2. Fibreglass Shop
3. Machine Shop
4. Control Room
5. Electrical Stores
6. Corridor
7. Ice Tank
8. Electrical Room
9. Basement

The ice tank carriage is about 14 m long and weighs approximately 80 tonnes with a natural frequency of about 12 Hz. The carriage is driven by electric motors and a rack and pinion system with two speed ranges: 0.000 m/s to 0.3 m/s and 0.02 m/s to 3 m/s. The maximum thrust available on the low speed range for testing fixed structures is 60 kN on the centreline and 30 kN on the quarter points. A Micro Vax 1 computer on the carriage is used for data collection and reduction. A separate service carriage is used for tasks such as melt surface clearing, seeding and sample testing of the ice sheet.

An underwater carriage, driven by the main carriage, supports underwater cameras which are used to record ice/hull interaction and ice flow beneath the model.

# 3. MODEL PREPARATION

## 3.1 General

A number of model configurations were tested. The base model is the existing ARCTIC, at a scale of 1:30, referred to as the "Base Beam, Base Midbody". This model was also tested with an additional midbody section and is referred to as the "Base Beam, Long Midbody". The second model is a copy of the base model with a 20% wider beam. This was tested with the same length as the "Base Beam, Base Midbody" and is referred to as the "Increased Beam, Base Midbody" and without a midbody section, referred to as the "Increased Beam, Short Midbody". The third configuration was a copy of the base model with a 20% narrower beam. This was tested with the same length as the "Base Beam, Base Midbody" referred to as the "Decreased Beam, Base Midbody" and two shorter lengths referred to as "Decreased Beam, Intermediate Midbody" and "Decreased Beam, Short Midbody".

The model tests were conducted in the ice tank of the Institute for Marine Dynamics (IMD) in St. John's, Newfoundland (Jones 1987). A new fibreglass/foam Base Beam stern was built for this program to replace the existing damaged stern. The seven parts for the increased and decreased beam models were constructed of foam and fibreglass using standard IMD procedures.

The models were painted with an IMRON paint system to achieve a target friction coefficient of 0.06. In addition to the model, two flat plates were also prepared for friction measurement purposes.

The hull lines, overall dimensions and non dimensional coefficients for the models and full size ships are presented in Appendix B1.

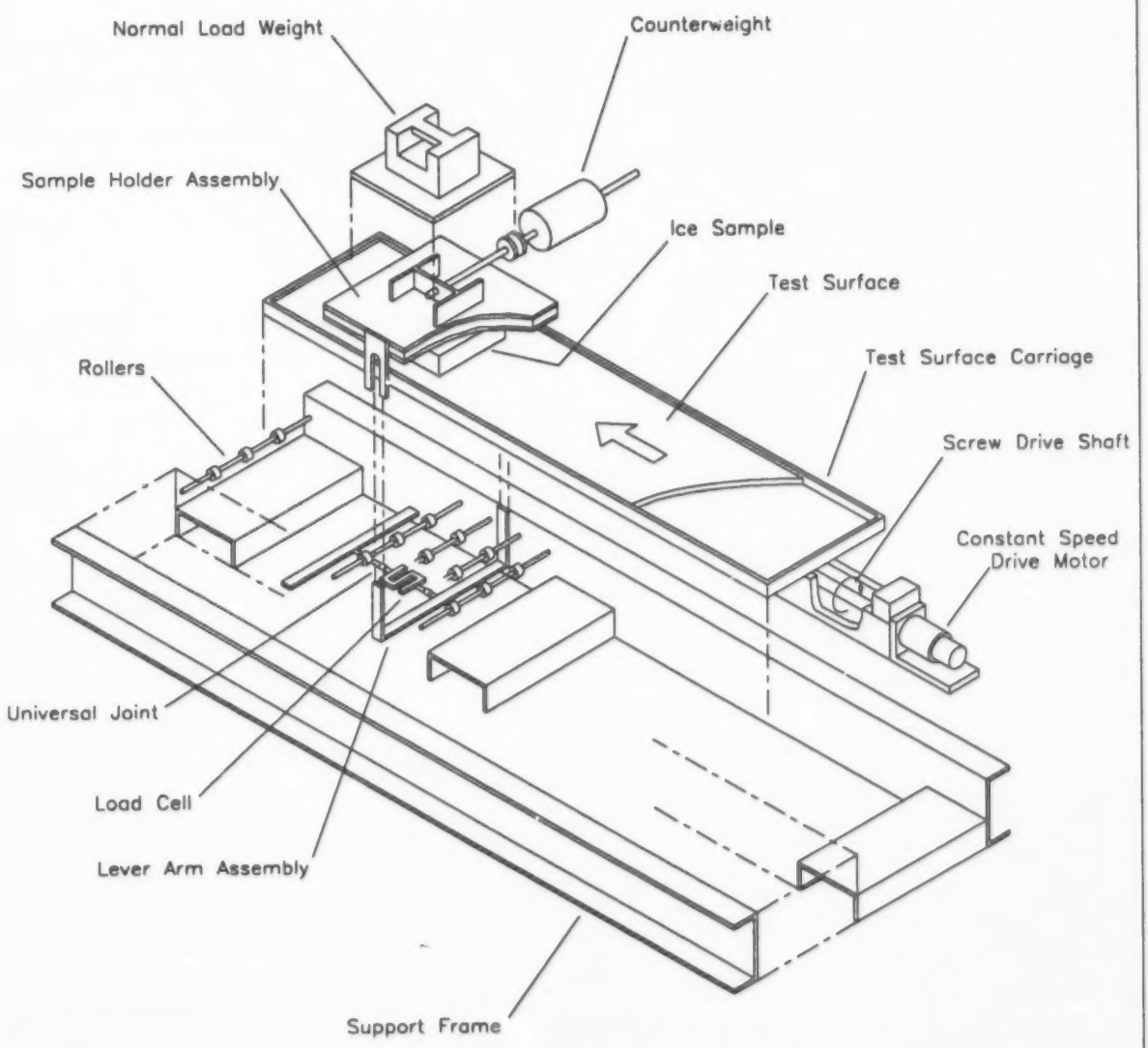
## 3.2 Friction Measurements

The objective of the friction tests was to measure the coefficient of friction between the surface of the model and the top surface of the model ice. The case of a sample of ice sliding over a long plate of model surface, where the ice piece continually encounters new surface, is thought to be most representative of broken ice pieces sliding along the bow and sides of the model. In order to measure the friction force in this type of interaction without measuring any effects of acceleration, the ice sample was held in place by a load cell and the flat plate, coated with the same paint finish as the model surface, was moved beneath it at a uniform speed.

The apparatus used to measure the friction force in the configuration described, referred to as the "Friction Jig", is shown in Figure 3.1. The Friction Jig consists of a

FIGURE 3.1

FRICTION JIG USED AT IMD



x 140 cm tray that holds the test plate. The tray is mounted at one end on a Unislide and at the other end is supported on four Teflon rollers. This allows the tray to be moved back and forth at a uniform speed. The slider is moved by a threaded rod, driven by an electric motor. The motor RPM can be held constant for a wide range of torques.

A sample of ice, with the bottom surface frozen to an aluminum sample holder, is placed on top of the model surface plate in the area where the tray is supported by the rollers. This allows a large normal load to be placed on the ice sample without any deflection of the tray. The ice sample holder is equipped with a counterweight which allows the weight of the ice sample and the sample holder to be counter balanced. The friction force measured is the force required to maintain the position of the balanced sample holder as the model surface plate moves beneath it.

Friction tests were conducted at a single speed of 10 cm/s. A thin film of water was applied to the model surface plate before each test, and therefore tests were, by definition, "wet" friction tests. A range of normal loads of 5, 10, 15, 20 and 25 kg were used on a 14 cm x 14 cm sample of model ice, yielding nominal normal pressures of 2.5, 5, 7.5, 10 and 12.5 kPa. Measurements were made at the same time as model tests whenever possible. The friction tests were all carried out in the ice tank room, where the temperature ranges from 0°C to +5°C during testing.

For a given ice sample, the friction force F is related to the normal force NF by; $F=\mu NF + SO$, where $\mu$ is the friction coefficient and SO is the static offset. Measurements for a particular surface with samples from different ice sheets usually yield similar values for $\mu$, although S may vary due to zero drift in the instrumentation and to ice sample differences.

In addition to the standard Friction Jig tests, samples of ice were also tested directly on the model components. These are referred to as "Plate" and "Model" test configurations respectively. This required some modification to the friction jig so tests were conducted on a sample panel (#5) using both procedures. The results of these tests, shown in Table 3.1, demonstrated that there was no significant difference between the two test methods.

The results from the Friction Jig and model component measurements are given in Appendix B2. The friction coefficient of each models is presented in Table 3.1.

## 3.3 Model Condition

The models were not outfitted with any appendages.

The overall dimensions and non dimensional coefficients for the models and full size ships are presented in Appendix B1.

The models were tested at one draught, equivalent to 10.98 m. at full scale.

### TABLE 3.1

### RESULTS OF FRICTION TESTS

| Model | Friction Coefficient | Comments |
|---|---|---|
| Base Beam | 0.1 | Based on Plate and Model Test Configuration |
| Increased Beam | 0.07 | Based on Plate and Model Test Configuration |
| Decreased Beam | 0.12 | Based on Model Test Configuration |
| Test Board #5 | 0.06 | Based on Test Plate Configuration |
| Test Board #5 | 0.07 | Based on Model Test Configuration |

# 4. LEVEL ICE RESISTANCE TESTS

## 4.1 Overview

The model tests, summarized in Table 4.1, were conducted at 1:30 scale to simulate thicknesses of 0.9 m and 1.2 m full scale. The target strength was selected based on the lowest practical model ice strength that could be achieved while maintaining ice quality. This was 25 kPa at model scale which was numerically corrected to 16.7 kPa

**TABLE 4.1**

**LEVEL ICE RESISTANCE TESTS**
**TARGET VALUES**

| Sheet # | Model Description | Target Ice Strength (kPa) | Target Ice Thickness (mm) | Test Speed (m/s) |
|---|---|---|---|---|
| 1 | Original Beam Original Length | 25 | 30 | 0.18, 0.33, 0.448, 0.602 |
| 2 | Decreased Beam Original Length | 25 | 30 | 0.18, 0.33, 0.448, 0.602 |
| 3 | Decreased Beam Intermediate Length | 25 | 30 | 0.18, 0.33, 0.448, 0.602 |
| 4 | Decreased Beam Short Length | 25 | 30 | 0.18, 0.33, 0.448, 0.602 |
| 5 | Original Beam Original Length | 25 | 40 | 0.18, 0.33, 0.448, 0.602 |
| 6 | Original Beam Long Length | 25 | 30 | 0.18, 0.33, 0.448, 0.602 |
| 7 | Increased Beam Original Length | 25 | 30 | 0.18, 0.33, 0.448, 0.602 |
| 8 | Increased Beam Short Length | 25 | 30 | 0.18, 0.33, 0.448, 0.602 |

to achieve a final full-scale value of 500 kPa. The test speeds were 0.18 m/s, 0.33 m/s, 0.47 m/s and 0.60 m/s which related to 1, 1.8, 2.5 and 3.3 m/sec full scale. These speeds were selected to correlate with previous model test programs. Presawn ice tests were conducted following all the tests at identical speeds to the conventional level ice resistance tests.

## 4.2 Model Test Procedures

Each model test followed a standard procedure shown in Figure 4.1 and described in the following notes;

- Prior to the test, the model is checked for the correct draught and, if necessary, an inclining experiment is conducted to establish the models Metacentric height and ballast adjusted accordingly.

- Using LVDT's (Linear Variable Displacement Transformer) attached to the model gimble, the natural period of pitch and roll is measured to calculate the radii of longitudinal and transverse gyration.

- The elastic modulus of the ice sheet is measured approximately half an hour before the target test time.

- Flexural strength tests are conducted on an ongoing basis to monitor the tempering of the ice sheet. These tests are also used to initiate the model test.

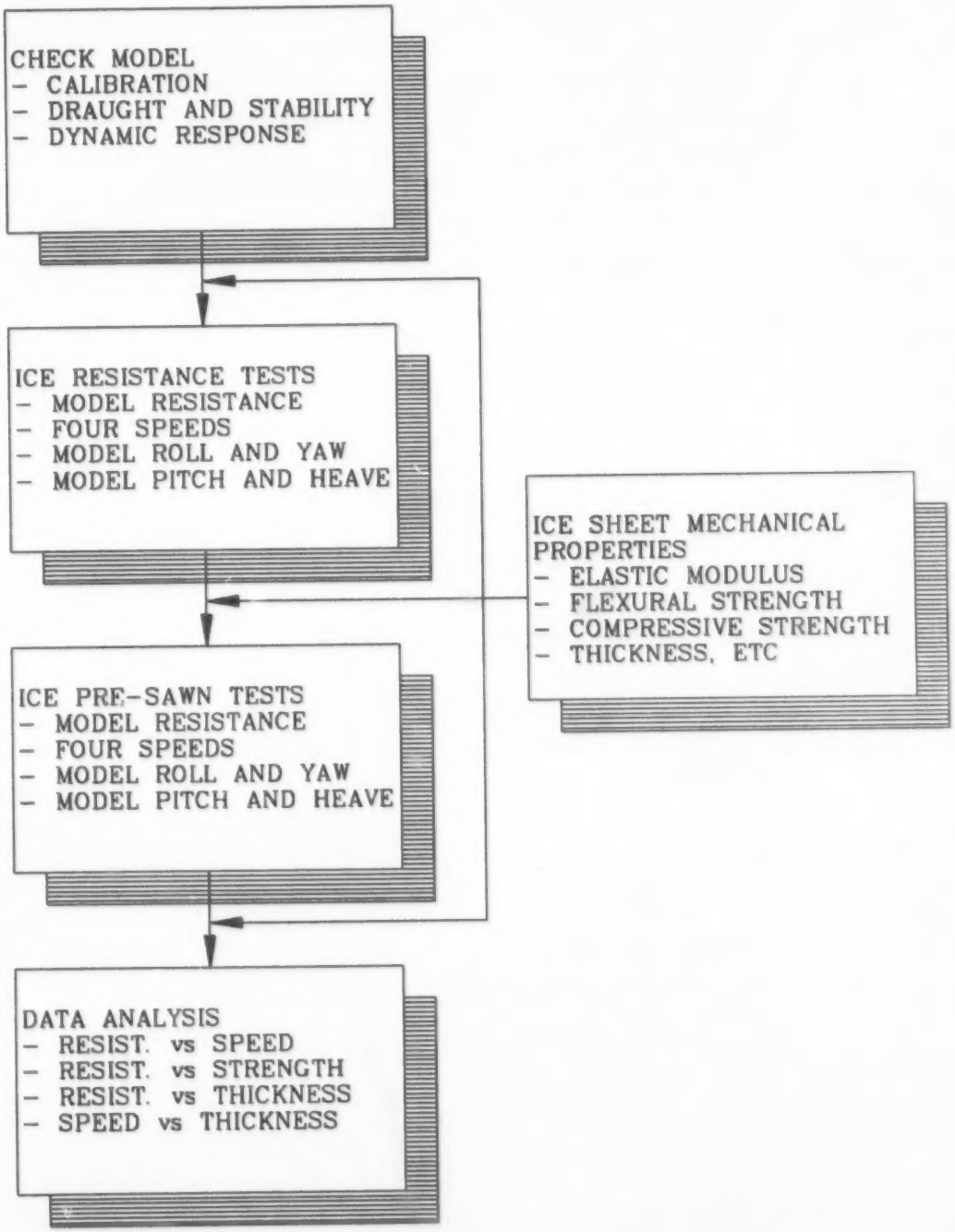
- The model is tested continuously down the centre of the tank at the required speeds. The data channels collected from the instrumentation for Resistance tests are:

  - Model resistance
  - Carriage speed
  - Model roll
  - Model heave
  - Model pitch

- Immediately following the resistance test, the carriage is returned to the start position. The mechanical properties of the ice sheet are then recorded in each test location, and the ice thickness and channel width is recorded every 2 m down the tank on either side of the resistance test broken track.

FIGURE 4.1

SCHEMATIC OF TEST PLAN PROCEDURE



- The remaining ice sheet is then prepared for presawn resistance tests. This is accomplished by reinforcing across the resistance broken track with wooden braces. This prevents the track from closing under the influence of presawn tests.

- The remaining ice sheet on one side of the resistance broken track is then prepared for presawn tests by cutting a track, equal to the width of the model plus "3 ice thicknesses". The track is cut in a "herringbone" pattern to resemble, as closely as possible, the broken floe size and shape of the resistance run.

- The model is then moved transversely across the tank to line up with the presawn channel and tested down the tank at the identical speeds as the resistance tests.

- Following the test the model is returned to the start position and the mechanical properties of the ice sheet are recorded together with the ice thickness every 2 m on either side of the presawn track.

## 4.3 Data Acquisition System

### 4.3.1 Model

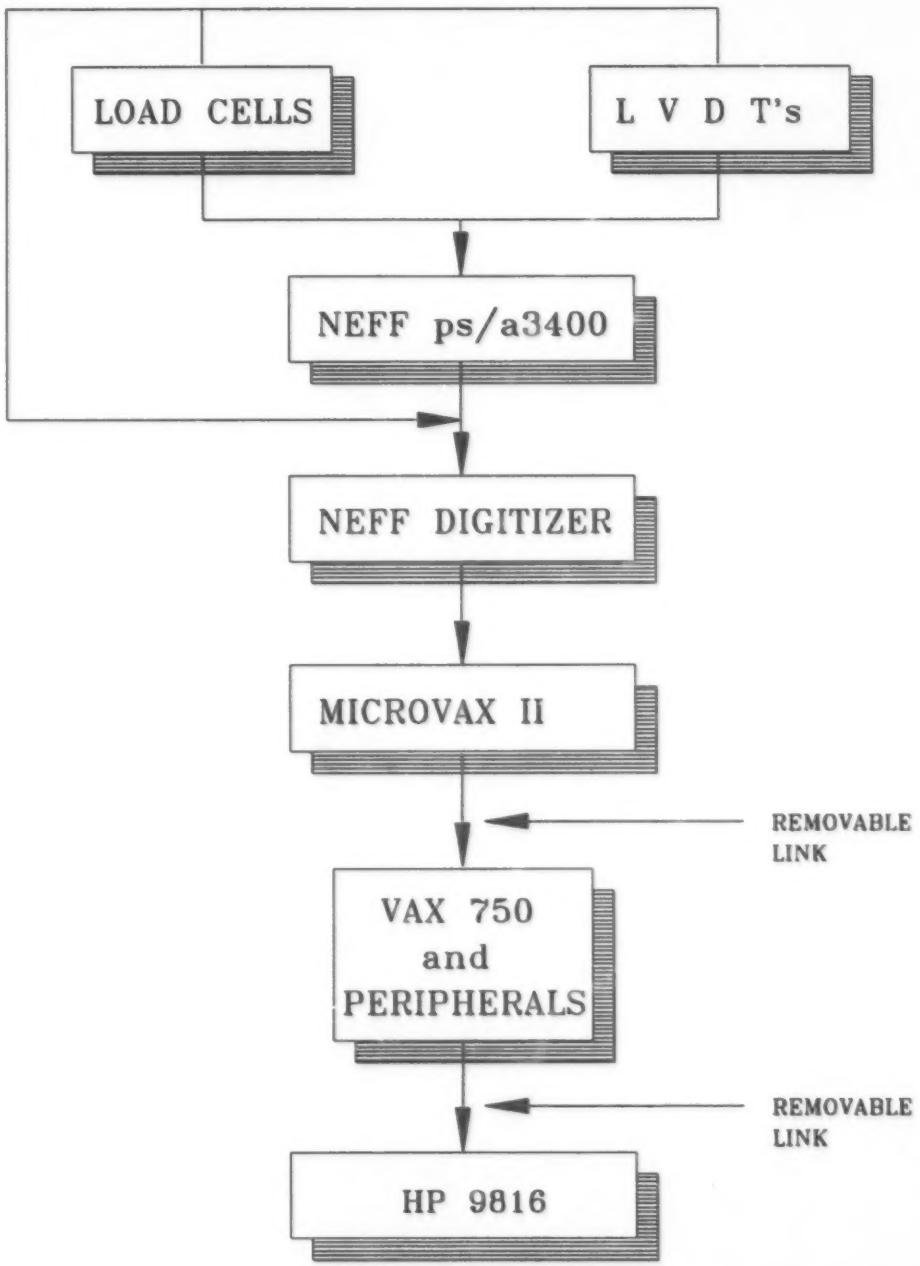
For the resistance tests, the model is propelled through the ice, at pre-defined speeds, by a gimble attached to the main carriage with a towing post.

The resistance, or tow force, is measured using a load cell built into the gimble. The model motions are measured using LVDT's mounted on the tow post. The power supply for these sensors is handled by a NEFF system. The amplification of the output and digitizing of the measured signals is performed by another NEFF system. The digitized data is formatted and stored on disk by a MicroVax computer system. For analysis and plotting, the data is transferred to a VAX 750 computer and subsequently to an HP 9816 computer. Figure 4.2 illustrates the schematic layout of the data acquisition system. The complete set of data collected for this program is presented in Appendix B3.

Throughout the tests, two underwater and two above water video cameras were used to record the breaking action at the bow, the midbody hull/ice interaction and the ice flow past the stern.

FIGURE 4.2

DATA AQUISITION SYSTEM



### 4.3.2 Ice

The ice sheets are monitored using conventional procedures developed by IMD. The data collected from each ice sheet is presented in Appendix C4.
The important variables on the ice data collection are:

a) Test Location:

The location of the test area, within each ice sheet, will be defined as shown in Figure 4.3. The areas are selected such that the model motions and speed are stable. The test area is at least the length of the model and is proceeded by a "settling in period" which is determined by scale. The model is completely surrounded by ice prior to a test.

b) Flexural Strength:

The flexural strength is measured using a floating cantilever beam cut from the ice sheet immediately following the primary test run. The cantilever beams will be loaded to failure with calibrated spring gauges and the maximum force during the failure is recorded. The beams have the overall ratio of dimensions for length, width and thickness of 5:2:1. Six beams are tested at about 800 mm from the model centreline. Beams are cut, tested, and measured immediately prior to and following the model test. Values of flexural strength are calculated based on an interpolation of the tempering curve from the cantilever results before and after the model test. The reported value of flexural strength is the average of the six beams tested in that particular test location.

c) Thickness:

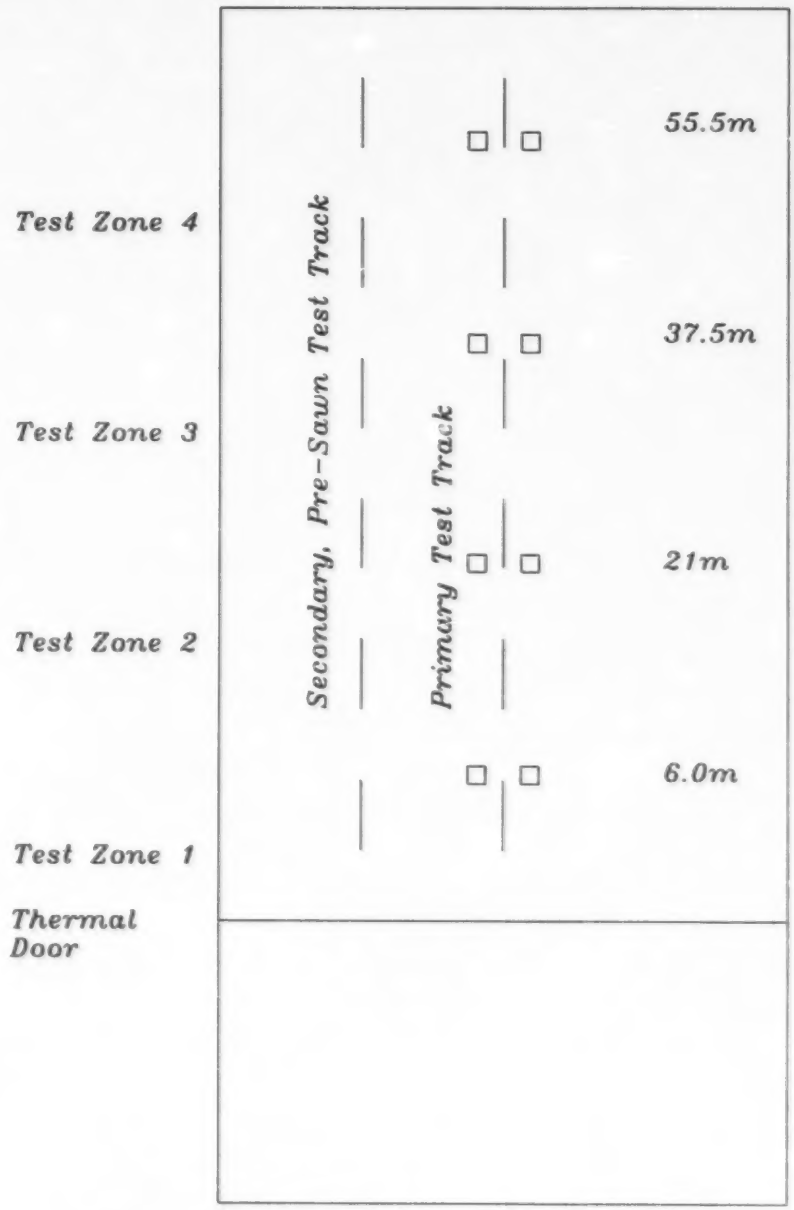
The ice thickness is measured, using callipers, immediately after the model test. The thickness is recorded at two meter intervals down the length of the ice tank. The ice samples are taken from both sides of the broken track left by the model.

d) Elastic Modulus:

The elastic modulus (characteristic length) is obtained 60 minutes prior to the test time by measuring deflection of the ice sheet with known forces.

FIGURE 4.3

ICE TANK TESTING LOCATIONS




| | | | |
|---|---|---|---|
| Flexural Strength (DOWN) | 6 | 6 | 6 |
| Compressive Strength | 6 | 6 | 6 |
| Thickness | . Every 2m, Both sides of primary track | | |
| Youngs Modulus | One measurement 60 minutes before test | | |

e) Compressive Strength:

Uniaxial crushing strength is measured 6 times within each test zone, or as time permits. The crushing strength is measured using a crushing jig that applies a uniaxial load to an ice sample of known cross section area.

f) Ice Density:

The ice density is recorded within 60 minutes of test time.

g) Channel Width:

The width of the resistance channel is measured every 2 m down the length of the tank to evaluate the extent of mid-body interaction that is taking place.

## 4.4 Data Analysis

The data analysis procedure adopted in this report has been developed by Dr. Bruce Colbourne of the Institute for Marine Dynamics (IMD). The analysis procedure permits the development of a regression line that may be used for presenting a resistance versus speed relationship.

The procedure involves the calculation of a non-dimensional breaking and clearing component of resistance which are plotted against an exponential function of the froude number for ice clearing and an "Ice strength number" for ice breaking.

The regression equations are in the form;

For icebreaking $R_b / (\rho B h V^2) = AB*(V/(\sigma/\rho)^{1/4})^{n2}$

and for ice clearing $R_c / (\rho B h V^2) = AC*(V/(gh)^{1/4})^{n1}$

A detailed discussion of how these relationships were developed is presented in Colbourne (1989).

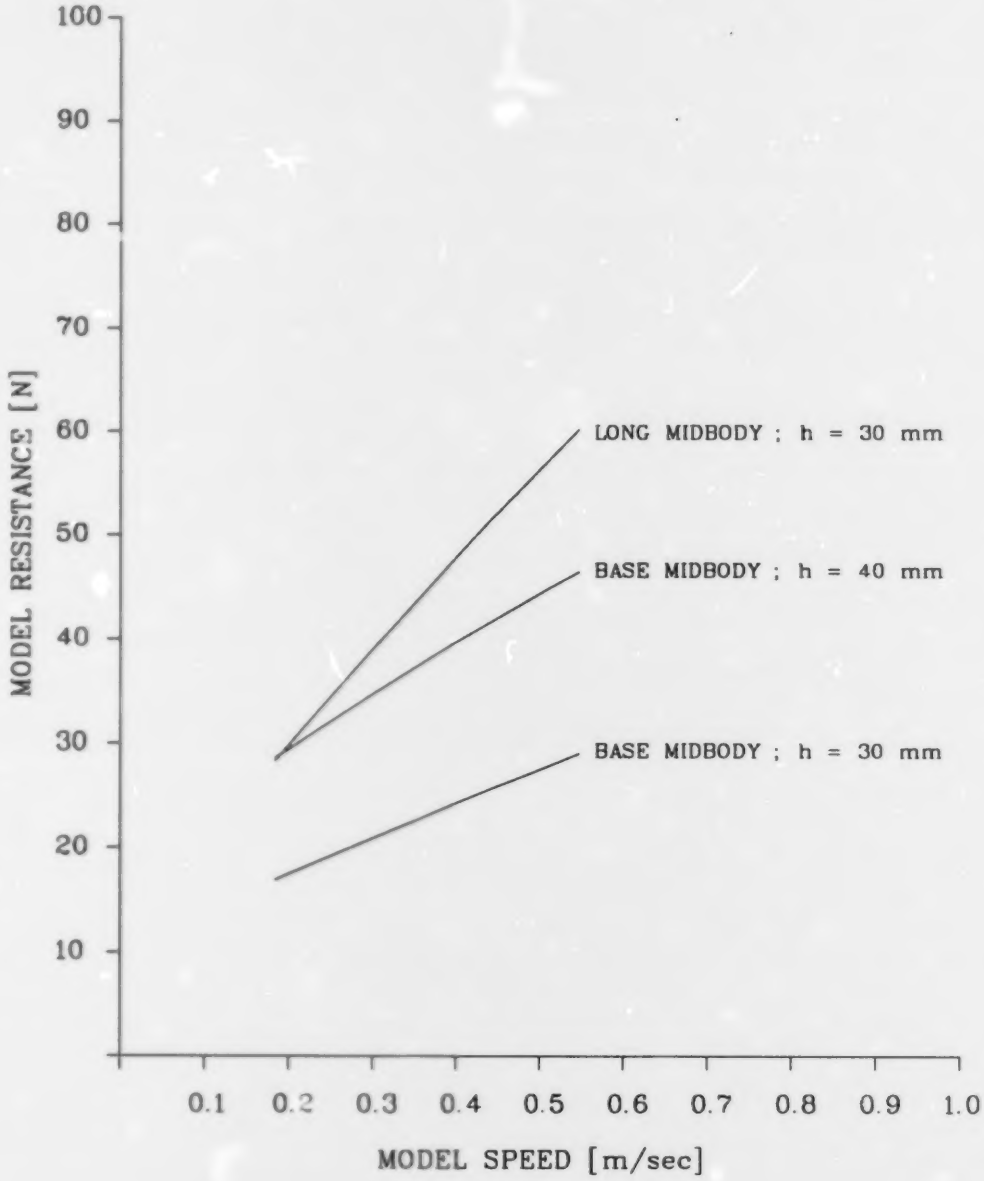
The coefficients derived from the analysis are presented in table B3.2.3.

## 4.5 Results

Using the coefficients developed in Section 4.4 it is possible to present model resistance curves for a strength of 16.7 kPa and thicknesses of 30 mm and 40mm. Figure 4.4 presents the model resistance data of the original base ship for each ice thickness. Figures 4.5, and 4.6 present the model resistance data for each beam as a function of speed over a range of speed.

FIGURE 4.4

MODEL RESISTANCE vs SPEED FOR THE BASE BEAM AND LENGTH

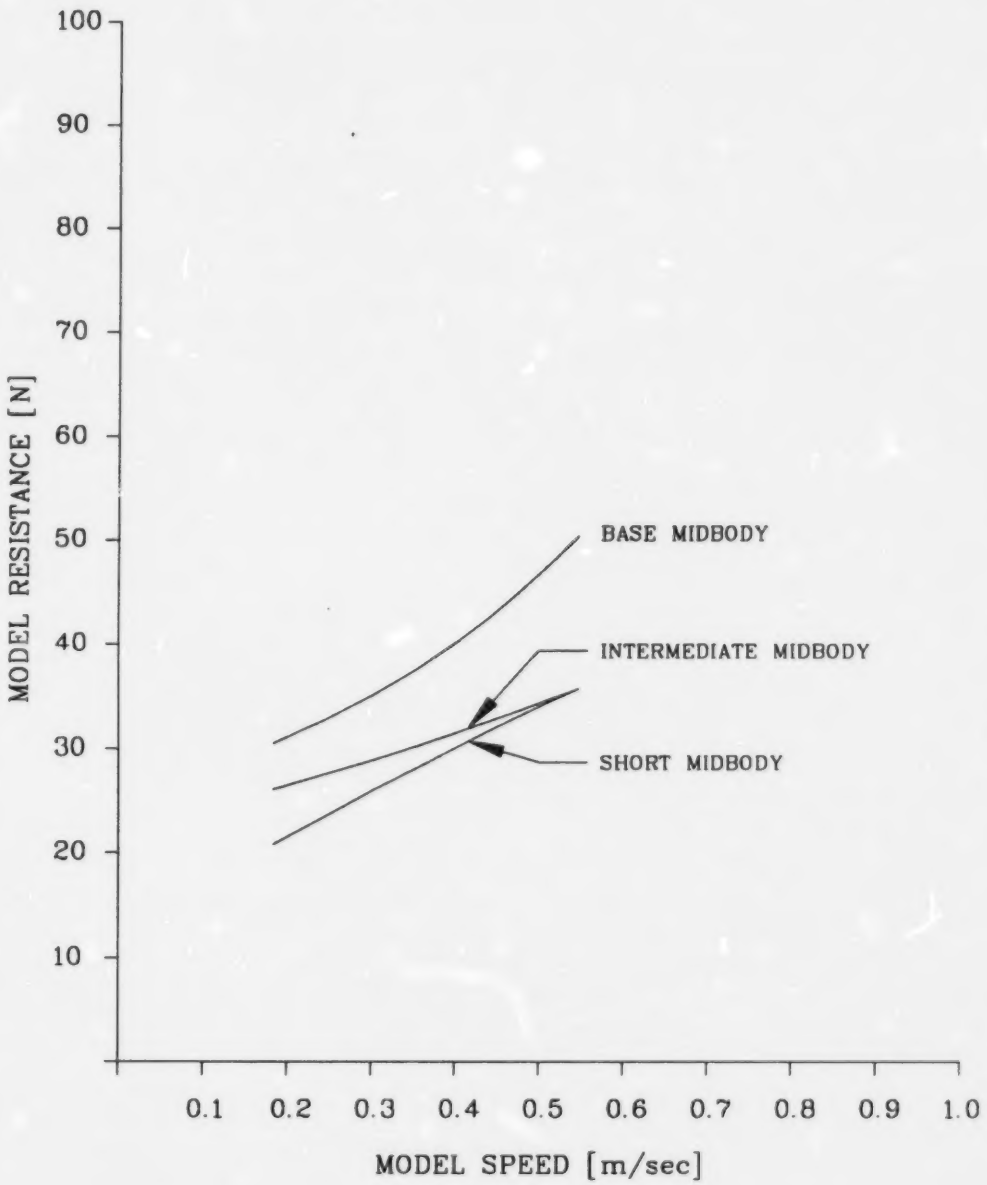



Target Ice Thickness = 30 and 40 mm
Target Ice Strength = 16.67
Friction Coefficient = 0.1

FIGURE 4.5

MODEL RESISTANCE vs SPEED FOR THE

DECREASED BEAM ORIGINAL, INTERMEDIATE AND SHORT MIDBODY




Target Ice Thickness = 30 mm

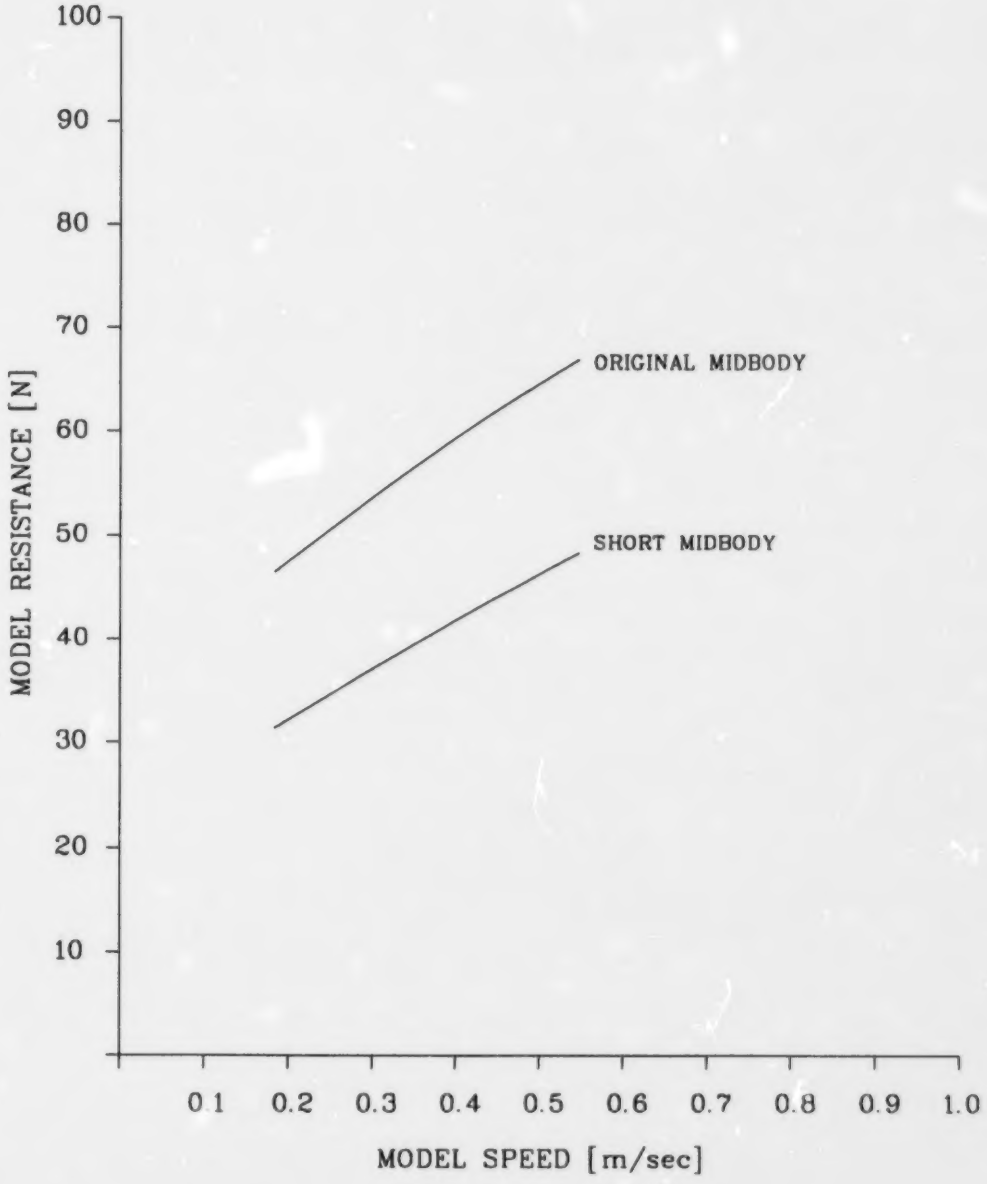
Target Ice Strength = 16.67

Friction Coefficient = 0.12

FIGURE 4.6

MODEL RESISTANCE vs SPEED FOR THE

INCREASED BEAM ORIGINAL AND SHORT MIDBODIES




Target Ice Thickness = 30 mm

Target Ice Strength = 16.67

Friction Coefficient = 0.07

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**Jones, S. J.** et al. Ice Tank Model Test Methods at IMD, IMD Report LM-AVR, May, 1987

**Timco, EG/AD/S**, A New Type of Model Ice for Refrigerated Towing Tanks, Cold Regions Science and Technology, October, 1985

# APPENDIX B1

# HYDROSTATICS AND HULL FORM COEFFICIENTS OF MODEL AND FULL SCALE SHIP

BASE BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR MODEL OF SCALE 1/ 30.000 WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 6.872 |
| LENGTH ON WATERLINE (LWL), m | 7.012 |
| WATERLINE BEAM AT MIDSHIPS, m | 0.762 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 0.762 |
| MAXIMUM WATERLINE BEAM, m | 0.762 |
| DRAUGHT AT MIDSHIPS, m | 0.366 |
| DRAUGHT AT MAXIMUM SECTION, m | 0.366 |
| MAXIMUM DRAUGHT, m | 0.366 |
| DRAUGHT ABOVE DATUM, m | 0.366 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -0.286 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 0.286 |
| TO, FORWARD OF MIDSHIPS, m | 1.360 |
| AREA OF MIDSHIPS STATION, SQ. m | 0.276 |
| AREA OF MAXIMUM STATION, SQ. m | 0.276 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.013 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -1.330 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 1.292 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 0.195 |
| WETTED SURFACE AREA, SQ. m | 8.084 |
| VOLUME OF DISPLACEMENT, CU. m | 1.396 |
| DISPLACEMENT, kg OF FRESH WATER | 1394.5 |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.019 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -1.541 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 1.515 |
| AREA OF WATERLINE PLANE, SQ. m | 4.582 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 0.141 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 10.361 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -0.150 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 0.187 |
| AREA OF PROFILE PLANE, SQ. m | 2.315 |

BASE BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR A FULL SIZED SHIP WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 206.16 |
| LENGTH ON WATERLINE (LWL), m | 210.36 |
| WATERLINE BEAM AT MIDSHIPS, m | 22.86 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 22.86 |
| MAXIMUM WATERLINE BEAM, m | 22.86 |
| DRAUGHT AT MIDSHIPS, m | 10.98 |
| DRAUGHT AT MAXIMUM SECTION, m | 10.98 |
| MAXIMUM DRAUGHT, m | 10.98 |
| DRAUGHT ABOVE DATUM, m | 10.98 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -8.58 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 8.58 |
| TO, FORWARD OF MIDSHIPS, m | 40.81 |
| AREA OF MIDSHIPS STATION, SQ. m | 248.73 |
| AREA OF MAXIMUM STATION, SQ. m | 248.73 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.40 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -39.90 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 38.77 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 5.84 |
| WETTED SURFACE AREA, SQ. m | 7275.66 |
| VOLUME OF DISPLACEMENT, CU. m | 37695.95 |
| DISPLACEMENT, t OF SALT WATER | 38672. |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.57 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -46.23 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 45.45 |
| AREA OF WATERLINE PLANE, SQ. m | 4123.90 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 4.23 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 310.83 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -4.50 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 5.62 |
| AREA OF PROFILE PLANE, SQ. m | 2083.55 |

BASE BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

COEFFICIENTS OF FORM FOR NAKED HULL

COEFFICIENTS BASED ON: LENGTH BETWEEN PERPENDICULARS
BEAM AT MIDSHIPS
DRAUGHT AT MIDSHIPS

| | |
|---|---|
| L/B | 9.018 |
| L/T | 18.776 |
| B/T | 2.082 |
| LWL (AFT BODY)/L | 0.521 |
| LWL (FORE BODY)/L | 0.500 |
| CB | 0.728 |
| CB OF THE AFT BODY | 0.725 |
| CB OF THE FORE BODY | 0.731 |
| CM | 0.991 |
| CX | 0.991 |
| CP | 0.735 |
| LCB %L FORWARD OF MIDSHIPS | -0.194 |
| LCB (AFT BODY) %L FORWARD OF MIDSHIPS | -19.352 |
| LCB (FORE BODY) %L FORWARD OF MIDSHIPS | 18.805 |
| CW | 0.875 |
| CW OF THE AFT BODY | 0.878 |
| CW OF THE FORE BODY | 0.872 |
| CIT | 0.777 |
| CIL | 0.702 |
| LCF %L FORWARD OF MIDSHIPS | -0.275 |
| LCF (AFT BODY) %L FORWARD OF MIDSHIPS | -22.426 |
| LCF (FORE BODY) %L FORWARD OF MIDSHIPS | 22.046 |
| BM/B | 0.185 |
| BML/L | 1.508 |
| BEAM - DISPLACEMENT RATIO (CIRCB) | 0.682 |
| DRAUGHT - DISPLACEMENT RATIO (CIRCT) | 0.327 |
| LENGTH - DISPLACEMENT RATIO (CIRCM) | 6.149 |
| WETTED SURFACE - DISPLACEMENT RATIO (CIRCS) | 6.472 |
| BM - DISPLACEMENT RATIO | 0.126 |
| BML - DISPLACEMENT RATIO | 9.270 |
| AREA OF PROFILE PLANE/LT | 0.920 |
| CLR %L FORWARD OF MIDSHIPS | -2.180 |

BASE BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

SUMMARY OF NORMALIZED STATION DATA

| STATION | AREA | BEAM | DEPTH |
|---|---|---|---|
| 0 | 0.017 | 0.207 | 0.153 |
| 1 | 0.182 | 0.510 | 1.000 |
| 2 | 0.422 | 0.737 | 1.000 |
| 3 | 0.624 | 0.886 | 1.000 |
| 4 | 0.778 | 0.969 | 1.000 |
| 5 | 0.883 | 0.999 | 1.000 |
| 6 | 0.946 | 1.000 | 1.000 |
| 7 | 0.980 | 1.000 | 1.000 |
| 8 | 0.996 | 1.000 | 1.000 |
| 9 | 1.000 | 1.000 | 1.000 |
| 10 | 1.000 | 1.000 | 1.000 |
| 11 | 1.000 | 1.000 | 1.000 |
| 12 | 1.000 | 1.000 | 1.000 |
| 13 | 1.000 | 1.000 | 1.000 |
| 14 | 1.000 | 1.000 | 1.000 |
| 15 | 0.986 | 1.000 | 1.000 |
| 16 | 0.902 | 0.995 | 1.000 |
| 17 | 0.654 | 0.930 | 1.000 |
| 18 | 0.276 | 0.793 | 1.000 |
| 19 | 0.067 | 0.471 | 0.338 |
| 20 | 0.000 | 0.000 | 0.000 |

AFT END OF WATERLINE IS AT -0.411
FORWARD END OF WATERLINE IS AT 19.997

AREA IS STATION AREA / MAXIMUM SECTION AREA
BEAM IS STATION BEAM / MAXIMUM WATERLINE BEAM
DEPTH IS STATION DEPTH / MAXIMUM DRAUGHT

BASE BEAM - INCREASED LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR MODEL OF SCALE 1/ 30.000 WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 8.600 |
| LENGTH ON WATERLINE (LWL), m | 8.740 |
| WATERLINE BEAM AT MIDSHIPS, m | 0.762 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 0.762 |
| MAXIMUM WATERLINE BEAM, m | 0.762 |
| DRAUGHT AT MIDSHIPS, m | 0.366 |
| DRAUGHT AT MAXIMUM SECTION, m | 0.366 |
| MAXIMUM DRAUGHT, m | 0.366 |
| DRAUGHT ABOVE DATUM, m | 0.366 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -1.131 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 1.131 |
| TO, FORWARD OF MIDSHIPS, m | 2.252 |
| AREA OF MIDSHIPS STATION, SQ. m | 0.276 |
| AREA OF MAXIMUM STATION, SQ. m | 0.276 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.007 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -1.742 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 1.717 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 0.192 |
| WETTED SURFACE AREA, SQ. m | 10.546 |
| VOLUME OF DISPLACEMENT, CU. m | 1.874 |
| DISPLACEMENT, kg OF FRESH WATER | 1871.5 |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.017 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -1.966 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 1.943 |
| AREA OF WATERLINE PLANE, SQ. m | 5.899 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 0.139 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 16.181 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -0.150 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 0.186 |
| AREA OF PROFILE PLANE, SQ. m | 2.948 |

BASE BEAM - INCREASED LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR A FULL SIZED SHIP WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 258.00 |
| LENGTH ON WATERLINE (LWL), m | 262.20 |
| WATERLINE BEAM AT MIDSHIPS, m | 22.86 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 22.86 |
| MAXIMUM WATERLINE BEAM, m | 22.86 |
| DRAUGHT AT MIDSHIPS, m | 10.98 |
| DRAUGHT AT MAXIMUM SECTION, m | 10.98 |
| MAXIMUM DRAUGHT, m | 10.98 |
| DRAUGHT ABOVE DATUM, m | 10.98 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -33.94 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 33.94 |
| TO, FORWARD OF MIDSHIPS, m | 67.57 |
| AREA OF MIDSHIPS STATION, SQ. m | 248.73 |
| AREA OF MAXIMUM STATION, SQ. m | 248.73 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.22 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -52.27 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 51.51 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 5.76 |
| WETTED SURFACE AREA, SQ. m | 9491.12 |
| VOLUME OF DISPLACEMENT, CU. m | 50589.86 |
| DISPLACEMENT, t OF SALT WATER | 51899. |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.50 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -58.98 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 58.30 |
| AREA OF WATERLINE PLANE, SQ. m | 5309.16 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 4.17 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 485.43 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -4.51 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 5.59 |
| AREA OF PROFILE PLANE, SQ. m | 2652.75 |

BASE BEAM - INCREASED LENGTH

DRAFT = 10.98 M NO TRIM

COEFFICIENTS OF FORM FOR NAKED HULL

COEFFICIENTS BASED ON: LENGTH BETWEEN PERPENDICULARS
BEAM AT MIDSHIPS
DRAUGHT AT MIDSHIPS

| | |
|---|---|
| L/B | 11.286 |
| L/T | 23.497 |
| B/T | 2.082 |
| LWL (AFT BODY)/L | 0.516 |
| LWL (FORE BODY)/L | 0.500 |
| CB | 0.781 |
| CB OF THE AFT BODY | 0.779 |
| CB OF THE FORE BODY | 0.784 |
| CM | 0.991 |
| CX | 0.991 |
| CP | 0.788 |
| LCB %L FORWARD OF MIDSHIPS | -0.084 |
| LCB (AFT BODY) %L FORWARD OF MIDSHIPS | -20.259 |
| LCB (FORE BODY) %L FORWARD OF MIDSHIPS | 19.967 |
| CW | 0.900 |
| CW OF THE AFT BODY | 0.903 |
| CW OF THE FORE BODY | 0.898 |
| CIT | 0.821 |
| CIL | 0.751 |
| LCF %L FORWARD OF MIDSHIPS | -0.195 |
| LCF (AFT BODY) %L FORWARD OF MIDSHIPS | -22.859 |
| LCF (FORE BODY) %L FORWARD OF MIDSHIPS | 22.598 |
| BM/B | 0.182 |
| BML/L | 1.881 |
| BEAM - DISPLACEMENT RATIO (CIRCB) | 0.618 |
| DRAUGHT - DISPLACEMENT RATIO (CIRCT) | 0.297 |
| LENGTH - DISPLACEMENT RATIO (CIRCM) | 6.976 |
| WETTED SURFACE - DISPLACEMENT RATIO (CIRCS) | 6.939 |
| BM - DISPLACEMENT RATIO | 0.113 |
| BML - DISPLACEMENT RATIO | 13.125 |
| AREA OF PROFILE PLANE/LT | 0.936 |
| CLR %L FORWARD OF MIDSHIPS | -1.749 |

BASE BEAM - INCREASED LENGTH

DRAFT = 10.98 M NO TRIM

SUMMARY OF NORMALIZED STATION DATA

| STATION | AREA | BEAM | DEPTH |
|---|---|---|---|
| 0 | 0.017 | 0.207 | 0.153 |
| 1 | 0.246 | 0.575 | 1.000 |
| 2 | 0.529 | 0.820 | 1.000 |
| 3 | 0.745 | 0.954 | 1.000 |
| 4 | 0.883 | 0.999 | 1.000 |
| 5 | 0.957 | 1.000 | 1.000 |
| 6 | 0.990 | 1.000 | 1.000 |
| 7 | 1.000 | 1.000 | 1.000 |
| 8 | 1.000 | 1.000 | 1.000 |
| 9 | 1.000 | 1.000 | 1.000 |
| 10 | 1.000 | 1.000 | 1.000 |
| 11 | 1.000 | 1.000 | 1.000 |
| 12 | 1.000 | 1.000 | 1.000 |
| 13 | 1.000 | 1.000 | 1.000 |
| 14 | 1.000 | 1.000 | 1.000 |
| 15 | 1.000 | 1.000 | 1.000 |
| 16 | 0.986 | 1.000 | 1.000 |
| 17 | 0.858 | 0.985 | 1.000 |
| 18 | 0.462 | 0.874 | 1.000 |
| 19 | 0.103 | 0.573 | 0.427 |
| 20 | 0.000 | 0.000 | 0.000 |

AFT END OF WATERLINE IS AT -0.328
FORWARD END OF WATERLINE IS AT 19.997

AREA IS STATION AREA / MAXIMUM SECTION AREA
BEAM IS STATION BEAM / MAXIMUM WATERLINE BEAM
DEPTH IS STATION DEPTH / MAXIMUM DRAUGHT

DECREASED BEAM - SHORT LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR MODEL OF SCALE 1/ 30.000 WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 4.583 |
| LENGTH ON WATERLINE (LWL), m | 4.723 |
| WATERLINE BEAM AT MIDSHIPS, m | 0.610 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 0.610 |
| MAXIMUM WATERLINE BEAM, m | 0.610 |
| DRAUGHT AT MIDSHIPS, m | 0.366 |
| DRAUGHT AT MAXIMUM SECTION, m | 0.366 |
| MAXIMUM DRAUGHT, m | 0.366 |
| DRAUGHT ABOVE DATUM, m | 0.366 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | 0.232 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | -0.232 |
| TO, FORWARD OF MIDSHIPS, m | 0.232 |
| AREA OF MIDSHIPS STATION, SQ. m | 0.219 |
| AREA OF MAXIMUM STATION, SQ. m | 0.221 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.034 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -0.812 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 0.742 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 0.202 |
| WETTED SURFACE AREA, SQ. m | 4.391 |
| VOLUME OF DISPLACEMENT, CU. m | 0.614 |
| DISPLACEMENT, kg OF FRESH WATER | 613.7 |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.022 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -0.988 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 0.955 |
| AREA OF WATERLINE PLANE, SQ. m | 2.271 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 0.094 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 4.798 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -0.148 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 0.190 |
| AREA OF PROFILE PLANE, SQ. m | 1.477 |

DECREASED BEAM - SHORT LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR A FULL SIZED SHIP WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 137.49 |
| LENGTH ON WATERLINE (LWL), m | 141.70 |
| WATERLINE BEAM AT MIDSHIPS, m | 18.29 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 18.29 |
| MAXIMUM WATERLINE BEAM, m | 18.29 |
| DRAUGHT AT MIDSHIPS, m | 10.98 |
| DRAUGHT AT MAXIMUM SECTION, m | 10.98 |
| MAXIMUM DRAUGHT, m | 10.98 |
| DRAUGHT ABOVE DATUM, m | 10.98 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | 6.97 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | -6.97 |
| TO, FORWARD OF MIDSHIPS, m | 6.97 |
| AREA OF MIDSHIPS STATION, SQ. m | 196.78 |
| AREA OF MAXIMUM STATION, SQ. m | 198.98 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -1.02 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -24.37 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 22.27 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 6.07 |
| WETTED SURFACE AREA, SQ. m | 3951.91 |
| VOLUME OF DISPLACEMENT, CU. m | 16588.71 |
| DISPLACEMENT, t OF SALT WATER | 17018. |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.67 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -29.65 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 28.64 |
| AREA OF WATERLINE PLANE, SQ. m | 2044.27 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 2.81 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 143.95 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -4.45 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 5.70 |
| AREA OF PROFILE PLANE, SQ. m | 1329.65 |

DECREASED BEAM - SHORT LENGTH

DRAFT = 10.98 M NO TRIM

COEFFICIENTS OF FORM FOR NAKED HULL

COEFFICIENTS BASED ON: LENGTH BETWEEN PERPENDICULARS
BEAM AT MIDSHIPS
DRAUGHT AT MIDSHIPS

| | |
|---|---|
| L/B | 7.518 |
| L/T | 12.522 |
| B/T | 1.666 |
| LWL (AFT BODY)/L | 0.531 |
| LWL (FORE BODY)/L | 0.500 |
| CB | 0.601 |
| CB OF THE AFT BODY | 0.600 |
| CB OF THE FORE BODY | 0.602 |
| CM | 0.980 |
| CX | 0.991 |
| CP | 0.606 |
| LCB %L FORWARD OF MIDSHIPS | -0.742 |
| LCB (AFT BODY) %L FORWARD OF MIDSHIPS | -17.726 |
| LCB (FORE BODY) %L FORWARD OF MIDSHIPS | 16.198 |
| CW | 0.813 |
| CW OF THE AFT BODY | 0.818 |
| CW OF THE FORE BODY | 0.808 |
| CIT | 0.665 |
| CIL | 0.603 |
| LCF %L FORWARD OF MIDSHIPS | -0.490 |
| LCF (AFT BODY) %L FORWARD OF MIDSHIPS | -21.569 |
| LCF (FORE BODY) %L FORWARD OF MIDSHIPS | 20.829 |
| BM/B | 0.154 |
| BML/L | 1.047 |
| BEAM - DISPLACEMENT RATIO (CIRCB) | 0.717 |
| DRAUGHT - DISPLACEMENT RATIO (CIRCT) | 0.431 |
| LENGTH - DISPLACEMENT RATIO (CIRCM) | 5.391 |
| WETTED SURFACE - DISPLACEMENT RATIO (CIRCS) | 6.076 |
| BM - DISPLACEMENT RATIO | 0.110 |
| BML - DISPLACEMENT RATIO | 5.644 |
| AREA OF PROFILE PLANE/LT | 0.881 |
| CLR %L FORWARD OF MIDSHIPS | -3.235 |

DECREASED BEAM - SHORT LENGTH

DRAFT = 10.98 M NO TRIM

SUMMARY OF NORMALIZED STATION DATA

| STATION | AREA | BEAM | DEPTH |
|---|---|---|---|
| 0 | 0.017 | 0.207 | 0.153 |
| 1 | 0.097 | 0.421 | 1.000 |
| 2 | 0.266 | 0.596 | 1.000 |
| 3 | 0.422 | 0.737 | 1.000 |
| 4 | 0.562 | 0.844 | 1.000 |
| 5 | 0.685 | 0.920 | 1.000 |
| 6 | 0.785 | 0.968 | 1.000 |
| 7 | 0.860 | 0.994 | 1.000 |
| 8 | 0.915 | 1.000 | 1.000 |
| 9 | 0.957 | 1.000 | 1.000 |
| 10 | 0.988 | 1.000 | 1.000 |
| 11 | 1.000 | 1.000 | 1.000 |
| 12 | 0.995 | 1.000 | 1.000 |
| 13 | 0.970 | 1.000 | 1.000 |
| 14 | 0.902 | 0.995 | 1.000 |
| 15 | 0.756 | 0.958 | 1.000 |
| 16 | 0.531 | 0.895 | 1.000 |
| 17 | 0.276 | 0.794 | 1.000 |
| 18 | 0.116 | 0.604 | 0.458 |
| 19 | 0.031 | 0.317 | 0.225 |
| 20 | 0.000 | 0.000 | 0.000 |

AFT END OF WATERLINE IS AT -0.616
FORWARD END OF WATERLINE IS AT 19.996

AREA IS STATION AREA / MAXIMUM SECTION AREA
BEAM IS STATION BEAM / MAXIMUM WATERLINE BEAM
DEPTH IS STATION DEPTH / MAXIMUM DRAUGHT

DECREASED BEAM - INTERMEDIATE LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR MODEL OF SCALE 1/ 30.000 WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 5.496 |
| LENGTH ON WATERLINE (LWL), m | 5.637 |
| WATERLINE BEAM AT MIDSHIPS, m | 0.610 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 0.610 |
| MAXIMUM WATERLINE BEAM, m | 0.610 |
| DRAUGHT AT MIDSHIPS, m | 0.366 |
| DRAUGHT AT MAXIMUM SECTION, m | 0.366 |
| MAXIMUM DRAUGHT, m | 0.366 |
| DRAUGHT ABOVE DATUM, m | 0.366 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -0.224 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 0.224 |
| TO, FORWARD OF MIDSHIPS, m | 0.689 |
| AREA OF MIDSHIPS STATION, SQ. m | 0.221 |
| AREA OF MAXIMUM STATION, SQ. m | 0.221 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.025 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -1.012 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 0.959 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 0.198 |
| WETTED SURFACE AREA, SQ. m | 5.570 |
| VOLUME OF DISPLACEMENT, CU. m | 0.816 |
| DISPLACEMENT, kg OF FRESH WATER | 815.4 |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.020 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -1.207 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 1.177 |
| AREA OF WATERLINE PLANE, SQ. m | 2.828 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 0.092 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 6.704 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -0.149 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 0.189 |
| AREA OF PROFILE PLANE, SQ. m | 1.812 |

DECREASED BEAM - INTERMEDIATE LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR A FULL SIZED SHIP WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 164.88 |
| LENGTH ON WATERLINE (LWL), m | 169.10 |
| WATERLINE BEAM AT MIDSHIPS, m | 18.29 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 18.29 |
| MAXIMUM WATERLINE BEAM, m | 18.29 |
| DRAUGHT AT MIDSHIPS, m | 10.98 |
| DRAUGHT AT MAXIMUM SECTION, m | 10.98 |
| MAXIMUM DRAUGHT, m | 10.98 |
| DRAUGHT ABOVE DATUM, m | 10.98 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -6.72 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 6.72 |
| TO, FORWARD OF MIDSHIPS, m | 20.68 |
| AREA OF MIDSHIPS STATION, SQ. m | 198.98 |
| AREA OF MAXIMUM STATION, SQ. m | 198.98 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.74 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -30.35 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 28.77 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 5.94 |
| WETTED SURFACE AREA, SQ. m | 5013.35 |
| VOLUME OF DISPLACEMENT, CU. m | 22040.44 |
| DISPLACEMENT, t OF SALT WATER | 22611. |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.61 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -36.20 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 35.31 |
| AREA OF WATERLINE PLANE, SQ. m | 2544.85 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 2.75 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 201.12 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -4.47 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 5.66 |
| AREA OF PROFILE PLANE, SQ. m | 1630.49 |

DECREASED BEAM - INTERMEDIATE LENGTH

DRAFT = 10.98 M NO TRIM

COEFFICIENTS OF FORM FOR NAKED HULL

COEFFICIENTS BASED ON: LENGTH BETWEEN PERPENDICULARS
BEAM AT MIDSHIPS
DRAUGHT AT MIDSHIPS

| | |
|---|---|
| L/B | 9.016 |
| L/T | 15.016 |
| B/T | 1.666 |
| LWL (AFT BODY)/L | 0.526 |
| LWL (FORE BODY)/L | 0.500 |
| CB | 0.666 |
| CB OF THE AFT BODY | 0.665 |
| CB OF THE FORE BODY | 0.667 |
| CM | 0.991 |
| CX | 0.991 |
| CP | 0.672 |
| LCB %L FORWARD OF MIDSHIPS | -0.451 |
| LCB (AFT BODY) %L FORWARD OF MIDSHIPS | -18.409 |
| LCB (FORE BODY) %L FORWARD OF MIDSHIPS | 17.451 |
| CW | 0.844 |
| CW OF THE AFT BODY | 0.848 |
| CW OF THE FORE BODY | 0.840 |
| CIT | 0.721 |
| CIL | 0.649 |
| LCF %L FORWARD OF MIDSHIPS | -0.370 |
| LCF (AFT BODY) %L FORWARD OF MIDSHIPS | -21.953 |
| LCF (FORE BODY) %L FORWARD OF MIDSHIPS | 21.414 |
| BM/B | 0.150 |
| BML/L | 1.220 |
| BEAM - DISPLACEMENT RATIO (CIRCB) | 0.652 |
| DRAUGHT - DISPLACEMENT RATIO (CIRCT) | 0.392 |
| LENGTH - DISPLACEMENT RATIO (CIRCM) | 5.881 |
| WETTED SURFACE - DISPLACEMENT RATIO (CIRCS) | 6.377 |
| BM - DISPLACEMENT RATIO | 0.098 |
| BML - DISPLACEMENT RATIO | 7.173 |
| AREA OF PROFILE PLANE/LT | 0.901 |
| CLR %L FORWARD OF MIDSHIPS | -2.708 |

DECREASED BEAM - INTERMEDIATE LENGTH

DRAFT = 10.98 M NO TRIM

SUMMARY OF NORMALIZED STATION DATA

| STATION | AREA | BEAM | DEPTH |
|---|---|---|---|
| 0 | 0.017 | 0.207 | 0.153 |
| 1 | 0.131 | 0.457 | 1.000 |
| 2 | 0.331 | 0.658 | 1.000 |
| 3 | 0.507 | 0.805 | 1.000 |
| 4 | 0.661 | 0.907 | 1.000 |
| 5 | 0.785 | 0.968 | 1.000 |
| 6 | 0.872 | 0.997 | 1.000 |
| 7 | 0.932 | 1.000 | 1.000 |
| 8 | 0.977 | 1.000 | 1.000 |
| 9 | 0.999 | 1.000 | 1.000 |
| 10 | 1.000 | 1.000 | 1.000 |
| 11 | 1.000 | 1.000 | 1.000 |
| 12 | 1.000 | 1.000 | 1.000 |
| 13 | 0.998 | 1.000 | 1.000 |
| 14 | 0.978 | 1.000 | 1.000 |
| 15 | 0.902 | 0.995 | 1.000 |
| 16 | 0.717 | 0.947 | 1.000 |
| 17 | 0.419 | 0.861 | 1.000 |
| 18 | 0.168 | 0.694 | 0.586 |
| 19 | 0.044 | 0.381 | 0.271 |
| 20 | 0.000 | 0.000 | 0.000 |

AFT END OF WATERLINE IS AT -0.513
FORWARD END OF WATERLINE IS AT 19.998

AREA IS STATION AREA / MAXIMUM SECTION AREA
BEAM IS STATION BEAM / MAXIMUM WATERLINE BEAM
DEPTH IS STATION DEPTH / MAXIMUM DRAUGHT

DECREASED BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR MODEL OF SCALE 1/ 30.000 WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 6.872 |
| LENGTH ON WATERLINE (LWL), m | 7.012 |
| WATERLINE BEAM AT MIDSHIPS, m | 0.610 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 0.610 |
| MAXIMUM WATERLINE BEAM, m | 0.610 |
| DRAUGHT AT MIDSHIPS, m | 0.366 |
| DRAUGHT AT MAXIMUM SECTION, m | 0.366 |
| MAXIMUM DRAUGHT, m | 0.366 |
| DRAUGHT ABOVE DATUM, m | 0.366 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -0.912 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 0.912 |
| TO, FORWARD OF MIDSHIPS, m | 1.377 |
| AREA OF MIDSHIPS STATION, SQ. m | 0.221 |
| AREA OF MAXIMUM STATION, SQ. m | 0.221 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.018 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -1.331 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 1.293 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 0.194 |
| WETTED SURFACE AREA, SQ. m | 7.335 |
| VOLUME OF DISPLACEMENT, CU. m | 1.120 |
| DISPLACEMENT, kg OF FRESH WATER | 1119.1 |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.018 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -1.541 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 1.515 |
| AREA OF WATERLINE PLANE, SQ. m | 3.666 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 0.090 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 10.333 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -0.150 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 0.187 |
| AREA OF PROFILE PLANE, SQ. m | 2.315 |

DECREASED BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR A FULL SIZED SHIP WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 206.16 |
| LENGTH ON WATERLINE (LWL), m | 210.36 |
| WATERLINE BEAM AT MIDSHIPS, m | 18.29 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 18.29 |
| MAXIMUM WATERLINE BEAM, m | 18.29 |
| DRAUGHT AT MIDSHIPS, m | 10.98 |
| DRAUGHT AT MAXIMUM SECTION, m | 10.98 |
| MAXIMUM DRAUGHT, m | 10.98 |
| DRAUGHT ABOVE DATUM, m | 10.98 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -27.36 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 27.36 |
| TO, FORWARD OF MIDSHIPS, m | 41.30 |
| AREA OF MIDSHIPS STATION, SQ. m | 198.98 |
| AREA OF MAXIMUM STATION, SQ. m | 198.98 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.53 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -39.94 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 38.80 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 5.83 |
| WETTED SURFACE AREA, SQ. m | 6601.54 |
| VOLUME OF DISPLACEMENT, CU. m | 30250.83 |
| DISPLACEMENT, t OF SALT WATER | 31034. |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.55 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -46.23 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 45.46 |
| AREA OF WATERLINE PLANE, SQ. m | 3299.45 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 2.70 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 309.99 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -4.50 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 5.62 |
| AREA OF PROFILE PLANE, SQ. m | 2083.55 |

DECREASED BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

COEFFICIENTS OF FORM FOR NAKED HULL

COEFFICIENTS BASED ON: LENGTH BETWEEN PERPENDICULARS
BEAM AT MIDSHIPS
DRAUGHT AT MIDSHIPS

| | |
|---|---|
| L/B | 11.273 |
| L/T | 18.776 |
| B/T | 1.666 |
| LWL (AFT BODY)/L | 0.521 |
| LWL (FORE BODY)/L | 0.500 |
| CB | 0.731 |
| CB OF THE AFT BODY | 0.730 |
| CB OF THE FORE BODY | 0.731 |
| CM | 0.991 |
| CX | 0.991 |
| CP | 0.737 |
| LCB %L FORWARD OF MIDSHIPS | -0.256 |
| LCB (AFT BODY) %L FORWARD OF MIDSHIPS | -19.371 |
| LCB (FORE BODY) %L FORWARD OF MIDSHIPS | 18.821 |
| CW | 0.875 |
| CW OF THE AFT BODY | 0.878 |
| CW OF THE FORE BODY | 0.872 |
| CIT | 0.777 |
| CIL | 0.702 |
| LCF %L FORWARD OF MIDSHIPS | -0.268 |
| LCF (AFT BODY) %L FORWARD OF MIDSHIPS | -22.426 |
| LCF (FORE BODY) %L FORWARD OF MIDSHIPS | 22.052 |
| BM/B | 0.148 |
| BML/L | 1.504 |
| BEAM - DISPLACEMENT RATIO (CIRCB) | 0.587 |
| DRAUGHT - DISPLACEMENT RATIO (CIRCT) | 0.352 |
| LENGTH - DISPLACEMENT RATIO (CIRCM) | 6.616 |
| WETTED SURFACE - DISPLACEMENT RATIO (CIRCS) | 6.800 |
| BM - DISPLACEMENT RATIO | 0.087 |
| BML - DISPLACEMENT RATIO | 9.949 |
| AREA OF PROFILE PLANE/LT | 0.920 |
| CLR %L FORWARD OF MIDSHIPS | -2.180 |

DECREASED BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

SUMMARY OF NORMALIZED STATION DATA

| STATION | AREA | BEAM | DEPTH |
|---|---|---|---|
| 0 | 0.017 | 0.207 | 0.153 |
| 1 | 0.182 | 0.510 | 1.000 |
| 2 | 0.422 | 0.737 | 1.000 |
| 3 | 0.625 | 0.886 | 1.000 |
| 4 | 0.785 | 0.968 | 1.000 |
| 5 | 0.889 | 0.999 | 1.000 |
| 6 | 0.957 | 1.000 | 1.000 |
| 7 | 0.997 | 1.000 | 1.000 |
| 8 | 1.000 | 1.000 | 1.000 |
| 9 | 1.000 | 1.000 | 1.000 |
| 10 | 1.000 | 1.000 | 1.000 |
| 11 | 1.000 | 1.000 | 1.000 |
| 12 | 1.000 | 1.000 | 1.000 |
| 13 | 1.000 | 1.000 | 1.000 |
| 14 | 1.000 | 1.000 | 1.000 |
| 15 | 0.986 | 1.000 | 1.000 |
| 16 | 0.902 | 0.995 | 1.000 |
| 17 | 0.654 | 0.930 | 1.000 |
| 18 | 0.276 | 0.794 | 1.000 |
| 19 | 0.067 | 0.471 | 0.338 |
| 20 | 0.000 | 0.000 | 0.000 |

AFT END OF WATERLINE IS AT -0.411
FORWARD END OF WATERLINE IS AT 19.997

AREA IS STATION AREA / MAXIMUM SECTION AREA
BEAM IS STATION BEAM / MAXIMUM WATERLINE BEAM
DEPTH IS STATION DEPTH / MAXIMUM DRAUGHT

INCREASED BEAM - SHORT LENGTH

DRAUGHT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR MODEL OF SCALE 1/ 30.000 WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 5.346 |
| LENGTH ON WATERLINE (LWL), m | 5.487 |
| WATERLINE BEAM AT MIDSHIPS, m | 0.914 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 0.914 |
| MAXIMUM WATERLINE BEAM, m | 0.914 |
| DRAUGHT AT MIDSHIPS, m | 0.366 |
| DRAUGHT AT MAXIMUM SECTION, m | 0.366 |
| MAXIMUM DRAUGHT, m | 0.366 |
| DRAUGHT ABOVE DATUM, m | 0.366 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | 0.483 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | -0.483 |
| TO, FORWARD OF MIDSHIPS, m | 0.614 |
| AREA OF MIDSHIPS STATION, SQ. m | 0.329 |
| AREA OF MAXIMUM STATION, SQ. m | 0.332 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.024 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -0.981 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 0.923 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 0.199 |
| WETTED SURFACE AREA, SQ. m | 6.510 |
| VOLUME OF DISPLACEMENT, CU. m | 1.170 |
| DISPLACEMENT, kg OF FRESH WATER | 1168.3 |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.020 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -1.171 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 1.141 |
| AREA OF WATERLINE PLANE, SQ. m | 4.105 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 0.208 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 6.394 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -0.149 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 0.189 |
| AREA OF PROFILE PLANE, SQ. m | 1.757 |

INCREASED BEAM - SHORT LENGTH

DRAUGHT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR A FULL SIZED SHIP WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 160.39 |
| LENGTH ON WATERLINE (LWL), m | 164.60 |
| WATERLINE BEAM AT MIDSHIPS, m | 27.43 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 27.43 |
| MAXIMUM WATERLINE BEAM, m | 27.43 |
| DRAUGHT AT MIDSHIPS, m | 10.98 |
| DRAUGHT AT MAXIMUM SECTION, m | 10.98 |
| MAXIMUM DRAUGHT, m | 10.98 |
| DRAUGHT ABOVE DATUM, m | 10.98 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | 14.48 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | -14.48 |
| TO, FORWARD OF MIDSHIPS, m | 18.43 |
| AREA OF MIDSHIPS STATION, SQ. m | 296.35 |
| AREA OF MAXIMUM STATION, SQ. m | 298.49 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.71 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -29.42 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 27.69 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 5.97 |
| WETTED SURFACE AREA, SQ. m | 5859.43 |
| VOLUME OF DISPLACEMENT, CU. m | 31580.94 |
| DISPLACEMENT, t OF SALT WATER | 32398. |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.61 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -35.12 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 34.22 |
| AREA OF WATERLINE PLANE, SQ. m | 3694.64 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 6.23 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 191.82 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -4.47 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 5.66 |
| AREA OF PROFILE PLANE, SQ. m | 1581.11 |

INCREASED BEAM - SHORT LENGTH

DRAUGHT = 10.98 M NO TRIM

COEFFICIENTS OF FORM FOR NAKED HULL

COEFFICIENTS BASED ON: LENGTH BETWEEN PERPENDICULARS
BEAM AT MIDSHIPS
DRAUGHT AT MIDSHIPS

| | |
|---|---|
| L/B | 5.847 |
| L/T | 14.608 |
| B/T | 2.498 |
| LWL (AFT BODY)/L | 0.526 |
| LWL (FORE BODY)/L | 0.500 |
| CB | 0.654 |
| CB OF THE AFT BODY | 0.650 |
| CB OF THE FORE BODY | 0.657 |
| CM | 0.984 |
| CX | 0.991 |
| CP | 0.660 |
| LCB %L FORWARD OF MIDSHIPS | -0.440 |
| LCB (AFT BODY) %L FORWARD OF MIDSHIPS | -18.342 |
| LCB (FORE BODY) %L FORWARD OF MIDSHIPS | 17.265 |
| CW | 0.840 |
| CW OF THE AFT BODY | 0.844 |
| CW OF THE FORE BODY | 0.836 |
| CIT | 0.713 |
| CIL | 0.642 |
| LCF %L FORWARD OF MIDSHIPS | -0.381 |
| LCF (AFT BODY) %L FORWARD OF MIDSHIPS | -21.893 |
| LCF (FORE BODY) %L FORWARD OF MIDSHIPS | 21.334 |
| BM/B | 0.227 |
| BML/L | 1.196 |
| BEAM - DISPLACEMENT RATIO (CIRCB) | 0.868 |
| DRAUGHT - DISPLACEMENT RATIO (CIRCT) | 0.347 |
| LENGTH - DISPLACEMENT RATIO (CIRCM) | 5.074 |
| WETTED SURFACE - DISPLACEMENT RATIO (CIRCS) | 5.865 |
| BM - DISPLACEMENT RATIO | 0.197 |
| BML - DISPLACEMENT RATIO | 6.069 |
| AREA OF PROFILE PLANE/LT | 0.898 |
| CLR %L FORWARD OF MIDSHIPS | -2.785 |

INCREASED BEAM - SHORT LENGTH

DRAUGHT = 10.98 M NO TRIM

SUMMARY OF NORMALIZED STATION DATA

| STATION | AREA | BEAM | DEPTH |
|---|---|---|---|
| 0 | 0.017 | 0.207 | 0.153 |
| 1 | 0.125 | 0.451 | 1.000 |
| 2 | 0.320 | 0.648 | 1.000 |
| 3 | 0.494 | 0.795 | 1.000 |
| 4 | 0.644 | 0.898 | 1.000 |
| 5 | 0.764 | 0.962 | 1.000 |
| 6 | 0.853 | 0.994 | 1.000 |
| 7 | 0.915 | 1.000 | 1.000 |
| 8 | 0.956 | 1.000 | 1.000 |
| 9 | 0.980 | 1.000 | 1.000 |
| 10 | 0.994 | 1.000 | 1.000 |
| 11 | 0.999 | 1.000 | 1.000 |
| 12 | 1.000 | 1.000 | 1.000 |
| 13 | 0.997 | 1.000 | 1.000 |
| 14 | 0.970 | 1.000 | 1.000 |
| 15 | 0.884 | 0.991 | 1.000 |
| 16 | 0.691 | 0.940 | 1.000 |
| 17 | 0.391 | 0.851 | 1.000 |
| 18 | 0.158 | 0.681 | 0.556 |
| 19 | 0.041 | 0.371 | 0.263 |
| 20 | 0.000 | 0.000 | 0.000 |

AFT END OF WATERLINE IS AT -0.528
FORWARD END OF WATERLINE IS AT 19.997

AREA IS STATION AREA / MAXIMUM SECTION AREA
BEAM IS STATION BEAM / MAXIMUM WATERLINE BEAM
DEPTH IS STATION DEPTH / MAXIMUM DRAUGHT

INCREASED BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR MODEL OF SCALE 1/ 30.000 WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 6.872 |
| LENGTH ON WATERLINE (LWL), m | 7.012 |
| WATERLINE BEAM AT MIDSHIPS, m | 0.914 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 0.914 |
| MAXIMUM WATERLINE BEAM, m | 0.914 |
| DRAUGHT AT MIDSHIPS, m | 0.366 |
| DRAUGHT AT MAXIMUM SECTION, m | 0.366 |
| MAXIMUM DRAUGHT, m | 0.366 |
| DRAUGHT ABOVE DATUM, m | 0.366 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -0.313 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 0.313 |
| TO, FORWARD OF MIDSHIPS, m | 1.377 |
| AREA OF MIDSHIPS STATION, SQ. m | 0.332 |
| AREA OF MAXIMUM STATION, SQ. m | 0.332 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.013 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -1.331 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 1.293 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 0.195 |
| WETTED SURFACE AREA, SQ. m | 8.889 |
| VOLUME OF DISPLACEMENT, CU. m | 1.675 |
| DISPLACEMENT, kg OF FRESH WATER | 1673.5 |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.018 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -1.541 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 1.515 |
| AREA OF WATERLINE PLANE, SQ. m | 5.499 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 0.203 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 10.364 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -0.150 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 0.187 |
| AREA OF PROFILE PLANE, SQ. m | 2.315 |

INCREASED BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

HYDROSTATIC PARTICULARS FOR A FULL SIZED SHIP WITHOUT APPENDAGES

| | |
|---|---|
| LENGTH BETWEEN PERPENDICULARS (LPP), m | 206.16 |
| LENGTH ON WATERLINE (LWL), m | 210.36 |
| WATERLINE BEAM AT MIDSHIPS, m | 27.43 |
| WATERLINE BEAM AT MAXIMUM SECTION, m | 27.43 |
| MAXIMUM WATERLINE BEAM, m | 27.43 |
| DRAUGHT AT MIDSHIPS, m | 10.98 |
| DRAUGHT AT MAXIMUM SECTION, m | 10.98 |
| MAXIMUM DRAUGHT, m | 10.98 |
| DRAUGHT ABOVE DATUM, m | 10.98 |
| MAXIMUM SECTION FORWARD OF MIDSHIPS, m | -9.39 |
| PARALLEL MIDDLE BODY, FROM, AFT OF MIDSHIPS, m | 9.39 |
| TO, FORWARD OF MIDSHIPS, m | 41.30 |
| AREA OF MIDSHIPS STATION, SQ. m | 298.49 |
| AREA OF MAXIMUM STATION, SQ. m | 298.49 |
| CENTRE OF BUOYANCY FORWARD OF MIDSHIPS (LCB), m | -0.40 |
| CENTRE OF AFT BODY BUOYANCY FORWARD OF MIDSHIPS, m | -39.92 |
| CENTRE OF FORE BODY BUOYANCY FORWARD OF MIDSHIPS, m | 38.80 |
| CENTRE OF BUOYANCY ABOVE DATUM , m | 5.84 |
| WETTED SURFACE AREA, SQ. m | 8000.49 |
| VOLUME OF DISPLACEMENT, CU. m | 45236.72 |
| DISPLACEMENT, t OF SALT WATER | 46408. |
| CENTRE OF FLOATATION FORWARD OF MIDSHIPS (LCF), m | -0.55 |
| CENTRE OF FLOATATION (AFT BODY), FORWARD OF MIDSHIPS, m | -46.23 |
| CENTRE OF FLOATATION (FORE BODY), FORWARD OF MIDSHIPS, m | 45.46 |
| AREA OF WATERLINE PLANE, SQ. m | 4949.13 |
| TRANSVERSE METACENTRIC RADIUS (BM), m | 6.09 |
| LONGITUDINAL METACENTRIC RADIUS (BML), m | 310.91 |
| CENTRE OF AREA OF PROFILE PLANE FORWARD OF MIDSHIPS (CLR), m | -4.50 |
| CENTRE OF AREA OF PROFILE PLANE ABOVE DATUM, m | 5.62 |
| AREA OF PROFILE PLANE, SQ. m | 2083.55 |

INCREASED BEAM ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

COEFFICIENTS OF FORM FOR NAKED HULL

COEFFICIENTS BASED ON: LENGTH BETWEEN PERPENDICULARS
BEAM AT MIDSHIPS
DRAUGHT AT MIDSHIPS

| | |
|---|---|
| L/B | 7.515 |
| L/T | 18.776 |
| B/T | 2.498 |
| LWL (AFT BODY)/L | 0.521 |
| LWL (FORE BODY)/L | 0.500 |
| CB | 0.728 |
| CB OF THE AFT BODY | 0.725 |
| CB OF THE FORE BODY | 0.731 |
| CM | 0.991 |
| CX | 0.991 |
| CP | 0.735 |
| LCB %L FORWARD OF MIDSHIPS | -0.192 |
| LCB (AFT BODY) %L FORWARD OF MIDSHIPS | -19.365 |
| LCB (FORE BODY) %L FORWARD OF MIDSHIPS | 18.821 |
| CW | 0.875 |
| CW OF THE AFT BODY | 0.878 |
| CW OF THE FORE BODY | 0.872 |
| CIT | 0.777 |
| CIL | 0.702 |
| LCF %L FORWARD OF MIDSHIPS | -0.267 |
| LCF (AFT BODY) %L FORWARD OF MIDSHIPS | -22.424 |
| LCF (FORE BODY) %L FORWARD OF MIDSHIPS | 22.052 |
| BM/B | 0.222 |
| BML/L | 1.508 |
| BEAM - DISPLACEMENT RATIO (CIRCB) | 0.770 |
| DRAUGHT - DISPLACEMENT RATIO (CIRCT) | 0.308 |
| LENGTH - DISPLACEMENT RATIO (CIRCM) | 5.786 |
| WETTED SURFACE - DISPLACEMENT RATIO (CIRCS) | 6.302 |
| BM - DISPLACEMENT RATIO | 0.071 |
| BML - DISPLACEMENT RATIO | 8.726 |
| AREA OF PROFILE PLANE/LT | 0.920 |
| CLR %L FORWARD OF MIDSHIPS | -2.180 |

INCREASED BEAM - ORIGINAL LENGTH

DRAFT = 10.98 M NO TRIM

SUMMARY OF NORMALIZED STATION DATA

| STATION | AREA | BEAM | DEPTH |
|---|---|---|---|
| 0 | 0.017 | 0.207 | 0.153 |
| 1 | 0.182 | 0.509 | 1.000 |
| 2 | 0.422 | 0.737 | 1.000 |
| 3 | 0.624 | 0.886 | 1.000 |
| 4 | 0.778 | 0.968 | 1.000 |
| 5 | 0.883 | 0.999 | 1.000 |
| 6 | 0.946 | 1.000 | 1.000 |
| 7 | 0.980 | 1.000 | 1.000 |
| 8 | 0.996 | 1.000 | 1.000 |
| 9 | 1.000 | 1.000 | 1.000 |
| 10 | 1.000 | 1.000 | 1.000 |
| 11 | 1.000 | 1.000 | 1.000 |
| 12 | 1.000 | 1.000 | 1.000 |
| 13 | 1.000 | 1.000 | 1.000 |
| 14 | 1.000 | 1.000 | 1.000 |
| 15 | 0.986 | 1.000 | 1.000 |
| 16 | 0.902 | 0.995 | 1.000 |
| 17 | 0.654 | 0.930 | 1.000 |
| 18 | 0.276 | 0.793 | 1.000 |
| 19 | 0.067 | 0.471 | 0.338 |
| 20 | 0.000 | 0.000 | 0.000 |

AFT END OF WATERLINE IS AT -0.411
FORWARD END OF WATERLINE IS AT 19.997

AREA IS STATION AREA / MAXIMUM SECTION AREA
BEAM IS STATION BEAM / MAXIMUM WATERLINE BEAM
DEPTH IS STATION DEPTH / MAXIMUM DRAUGHT

# APPENDIX B2

# FRICTION TEST RESULTS

# FRICTION TEST RESULTS

The results from the friction tests are presented on standard data sheets. The sheets give the date and ice conditions during the friction tests. Friction tests were done on two test boards which were representative of the model surface. Tests were also conducted on the actual model surface.

The horizontal force, or friction force, experienced by the ice is recorded using a pen plotter which has been previously calibrated with known weights. As a result the horizontal force is first recorded as divisions which must then be converted into units of force using the calibration results. The calibration and friction test records are presented on the data sheets together with the final vertical vs. horizontal force linear equation in the form.

Horizontal force = Constant + Friction Coefficient x (Vertical Force)

## FRICTION TEST DATA SHEET

Date: June 6, 1989

Ice Thickness: 30 mm

Ice Strength: 23.0 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0 | 5.0 |
| 0.3 | 8.0 |
| 0.8 | 12.2 |
| 1.3 | 17.0 |
| 1.8 | 21.2 |
| 2.3 | 25.5 |
| 2.8 | 30.0 |
| 3.3 | 33.5 |

Least Squares Regression

Horizontal Load = -0.612 + 0.115 x (Division)

Time: 10:55 Model: Board #5

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 0 | | |
| 5 | 11.5 | 0.708 |
| 10 | 14.5 | 1.053 |
| 15 | 17.0 | 1.340 |
| 20 | 20.0 | 1.684 |
| 25 | 22.5 | 1.971 |
| 30 | 25.5 | 2.315 |

Least Squares Regression

Horizontal Load = + 0.399 + 0.064 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 6, 1989

Ice Thickness: 30 mm

Ice Strength: 23.0 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0 | 5.0 |
| 0.3 | 8.0 |
| 0.8 | 12.2 |
| 1.3 | 17.0 |
| 1.8 | 21.2 |
| 2.3 | 25.5 |
| 2.8 | 30.0 |
| 3.3 | 33.5 |

Least Squares Regression

Horizontal Load = -0.612 + 0.115 x (Division)

Time: 12:50 Model: Board #5

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 0 | | |
| 5 | 7.8 | 0.284 |
| 10 | 11.0 | 0.651 |
| 15 | 13.5 | 0.938 |
| 20 | 16.6 | 1.294 |
| 25 | 20.9 | 1.787 |
| 30 | 23.1 | 2.040 |

Least Squares Regression

Horizontal Load = - 0.089 + 0.072 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 6, 1989

Ice Thickness: 30 mm

Ice Strength: 23.0 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0 | 5.0 |
| 0.3 | 8.0 |
| 0.8 | 12.2 |
| 1.3 | 17.0 |
| 1.8 | 21.2 |
| 2.3 | 25.5 |
| 2.8 | 30.0 |
| 3.3 | 33.5 |

Least Squares Regression

Horizontal Load = - 0.612 + 0.115 x (Division)

Time: 11:08 Model: Board #6

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 0 | | |
| 5 | 13.2 | 0.903 |
| 10 | 16.8 | 1.317 |
| 15 | 20.8 | 1.776 |
| 20 | 25.0 | 2.258 |
| 25 | 29.0 | 2.717 |
| 30 | 33.0 | 3.176 |

Least Squares Regression

Horizontal Load = + 0.420 + 0.092 x (vertical load)

# FRICTION TEST DATA SHEET

Date: June 6, 1989

Ice Thickness: 30 mm

Ice Strength: 23.0 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0 | 5.0 |
| 0.3 | 8.0 |
| 0.8 | 12.2 |
| 1.3 | 17.0 |
| 1.8 | 21.2 |
| 2.3 | 25.5 |
| 2.8 | 30.0 |
| 3.3 | 33.5 |

Least Squares Regression

Horizontal Load = - 0.612 + 0.115 x (Division)

Time: 12:40 Model: Board #6

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 0 | | |
| 5 | 9.2 | 0.444 |
| 10 | 13.0 | 0.880 |
| 15 | 17.2 | 1.363 |
| 20 | 21.4 | 1.845 |
| 25 | 25.8 | 2.350 |
| 30 | 30.8 | 2.924 |

Least Squares Regression

Horizontal Load = - 0.095 + 0.099 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 7, 1989

Ice Thickness: 29.5mm

Ice Strength: 25.0 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0 | 5.0 |
| 0.3 | 7.5 |
| 0.8 | 12.2 |
| 1.3 | 17.2 |
| 1.8 | 21.5 |
| 2.3 | 26.0 |
| 2.8 | 30.0 |
| 3.3 | 35.0 |

Least Squares Regression

Horizontal Load = - 0.552 + 0.110 x (Division)

Time: 11:42 Model: Board #5

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 0 | | |
| 5 | 7.0 | 0.219 |
| 10 | 10.0 | 0.550 |
| 15 | 12.5 | 0.826 |
| 20 | 16.0 | 1.221 |
| 25 | 19.0 | 1.542 |
| 30 | 22.0 | 1.873 |

Least Squares Regression

Horizontal Load = - 0.126 + 0.066 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 7, 1989

Ice Thickness: 29.5mm

Ice Strength: 25.0 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0 | 5.0 |
| 0.3 | 7.5 |
| 0.8 | 12.2 |
| 1.3 | 17.2 |
| 1.8 | 21.5 |
| 2.3 | 26.0 |
| 2.8 | 30.0 |
| 3.3 | 35.0 |

Least Squares Regression

Horizontal Load = - 0.552 + 0.110 x (Division)

Time: 11:55 Model: Board #6

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 0 | | |
| 5 | 7.0 | 0.219 |
| 10 | 11.5 | 0.715 |
| 15 | 15.5 | 1.156 |
| 20 | 19.5 | 1.597 |
| 25 | 23.5 | 2.038 |
| 30 | 27.5 | 2.479 |

Least Squares Regression

Horizontal Load = - 0.204 + 0.090 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 8, 1989

Ice Thickness: 28.9mm

Ice Strength: 25.0 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0 | 5.0 |
| 0.3 | 8.0 |
| 0.8 | 12.8 |
| 1.3 | 17.0 |
| 1.8 | 21.0 |
| 2.3 | 25.0 |
| 2.8 | 29.5 |
| 3.3 | 33.8 |
| 3.8 | 37.8 |

Least Squares Regression

Horizontal Load = - 0.643 + 0.117 x (Division)

Time: 11:40 Model: Board #5

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 0 | | |
| 5 | 4.0 | -0.175 |
| 10 | 7.0 | 0.715 |
| 15 | 10.0 | 0.526 |
| 20 | 13.0 | 0.876 |
| 25 | 16.5 | 1.285 |
| 30 | 20.0 | 1.694 |
| 35 | 23.0 | 2.044 |

Least Squares Regression

Horizontal Load = - 0.576 + 0.075 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 8, 1989

Ice Thickness: 28.9mm

Ice Strength: 25.0 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0 | 5.0 |
| 0.3 | 8.0 |
| 0.8 | 12.8 |
| 1.3 | 17.0 |
| 1.8 | 21.0 |
| 2.3 | 25.0 |
| 2.8 | 29.5 |
| 3.3 | 33.8 |
| 3.8 | 37.8 |

Least Squares Regression

Horizontal Load = - 0.643 + 0.117 x (Division)

Time: 11:55 Model: Board #6

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 0 | | |
| 5 | 8.5 | 0.350 |
| 10 | 12.0 | 0.759 |
| 15 | 16.0 | 1.226 |
| 20 | 20.0 | 1.694 |
| 25 | 24.5 | 2.161 |
| 30 | 28.0 | 2.628 |
| 35 | 32.0 | 3.096 |

Least Squares Regression

Horizontal Load = - 0.142 + 0.092 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 13, 1989

Ice Thickness: 40mm

Ice Strength: 20 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.0 |
| 0.833 | 12.0 |
| 1.333 | 15.8 |
| 1.833 | 19.5 |
| 2.333 | 23.2 |
| 2.833 | 27.0 |
| 3.333 | 31.0 |
| 3.833 | 36.0 |
| 4.333 | 39.0 |
| 4.833 | 43.0 |
| 5.333 | 46.9 |

Least Squares Regression

Horizontal Load = - 0.72 + 0.13 x (Division)

Time: 12:20 Model: Board #326B$^{IV}$

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 3.0034 | 8.0 | 0.31 |
| 8.0034 | 12.5 | 0.89 |
| 13.0034 | 17.3 | 1.51 |
| 18.0034 | 22.0 | 2.12 |
| 23.0034 | 26.7 | 2.72 |
| 28.0034 | 30.8 | 3.25 |
| 33.0034 | 35.0 | 3.79 |
| 38.0034 | 40.0 | 4.43 |
| 43.0034 | 44.2 | 4.98 |

Least Squares Regression

Horizontal Load = - 0.016 + 0.117 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 13, 1989

Ice Thickness: 40mm

Ice Strength: 20 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.0 |
| 0.833 | 12.0 |
| 1.333 | 15.8 |
| 1.833 | 19.5 |
| 2.333 | 23.2 |
| 2.833 | 27.0 |
| 3.333 | 31.0 |
| 3.833 | 35.0 |
| 4.333 | 39.0 |
| 4.833 | 43.0 |
| 5.333 | 46.9 |

Least Squares Regression

Horizontal Load = - 0.72 + 0.13 x (Division)

Time: 12:43 Model: Board #326B[IV]

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.9745 | 7.5 | 0.25 |
| 7.9745 | 12.2 | 0.85 |
| 12.9745 | 16.0 | 1.34 |
| 17.9745 | 21.0 | 1.99 |
| 22.9745 | 25.0 | 2.50 |
| 27.9745 | 30.0 | 3.15 |
| 32.9745 | 34.2 | 3.89 |
| 37.9745 | 39.0 | 4.31 |
| 42.9745 | 43.0 | 4.82 |

Least Squares Regression

Horizontal Load = - 0.0945 + 0.1144 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 14, 1989

Ice Thickness: 28.7mm

Ice Strength: 26 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.2 |
| 0.833 | 12.5 |
| 1.333 | 17.0 |
| 1.833 | 21.0 |
| 2.333 | 25.3 |
| 2.833 | 29.8 |
| 3.333 | 34.0 |
| 3.833 | 38.2 |
| 4.333 | 42.7 |
| 4.833 | 47.0 |

Least Squares Regression

Horizontal Load = - 0.62 + 0.12 x (Division)

Time: 13:02 Model: Board #5

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.888 | 6.0 | 0.08 |
| 7.888 | 9.0 | 0.45 |
| 12.888 | 11.9 | 0.76 |
| 17.888 | 15.0 | 1.12 |
| 22.888 | 18.0 | 1.47 |
| 27.888 | 21.0 | 1.82 |
| 32.888 | 23.0 | 2.05 |

Least Squares Regression

Horizontal Load = - 0.09 + 0.07 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 14, 1989

Ice Thickness: 28.7mm

Ice Strength: 26 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.2 |
| 0.833 | 12.5 |
| 1.333 | 17.0 |
| 1.833 | 21.0 |
| 2.333 | 25.3 |
| 2.833 | 29.8 |
| 3.333 | 34.0 |
| 3.833 | 38.2 |
| 4.333 | 42.7 |
| 4.833 | 47.0 |

Least Squares Regression

Horizontal Load = - 0.62 + 0.12 x (Division)

Time: 13:02 Model: Board #5

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.888 | 5.8 | 0.05 |
| 7.888 | 8.5 | 0.37 |
| 12.888 | 11.5 | 0.72 |
| 17.888 | 14.0 | 1.01 |
| 22.888 | 16.5 | 1.30 |
| 27.888 | 19.0 | 1.59 |
| 32.888 | 21.5 | 1.88 |
| 37.888 | 24.5 | 2.23 |

Least Squares Regression

Horizontal Load = - 0.10 + 0.06 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 14, 1989

Ice Thickness: 28.7mm

Ice Strength: 26 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.2 |
| 0.833 | 12.5 |
| 1.333 | 17.0 |
| 1.833 | 21.0 |
| 2.333 | 25.3 |
| 2.833 | 29.8 |
| 3.333 | 34.0 |
| 3.833 | 38.2 |
| 4.333 | 42.7 |
| 4.833 | 47.0 |

Least Squares Regression

Horizontal Load = - 0.62 + 0.12 x (Division)

Time: Model: Decreased beam, long midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.804 | 7.0 | 0.19 |
| 7.804 | 13.0 | 0.89 |
| 12.804 | 18.0 | 1.47 |
| 17.804 | 23.0 | 2.05 |
| 22.804 | 28.5 | 2.69 |
| 27.804 | 34.0 | 3.33 |
| 32.804 | 39.0 | 3.91 |
| 37.804 | 44.5 | 4.55 |

Least Squares Regression

Horizontal Load = - 0.12 + 0.12 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 15, 1989

Ice Thickness: 30.1mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.3 |
| 0.833 | 12.8 |
| 1.333 | 17.0 |
| 1.833 | 21.4 |
| 2.333 | 25.5 |
| 2.833 | 30.0 |
| 3.333 | 34.2 |
| 3.833 | 38.6 |
| 4.333 | 43.0 |

Least Squares Regression

Horizontal Load = - 0.635 + 0.1157 x (Division)

Time: 10:50 Model: Base beam, short midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 7.858 | 15.2 | 1.1242 |
| 12.858 | 21.5 | 1.8533 |
| 17.858 | 28.5 | 2.6635 |
| 22.858 | 34.0 | 3.300 |
| 27.858 | 41.0 | 4.1102 |
| 32.858 | 47.5 | 4.8624 |

Least Squares Regression

Horizontal Load = - 0.0504 + 0.1491 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 15, 1989

Ice Thickness: 30.1mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.3 |
| 0.833 | 12.8 |
| 1.333 | 17.0 |
| 1.833 | 21.4 |
| 2.333 | 25.5 |
| 2.833 | 30.0 |
| 3.333 | 34.2 |
| 3.833 | 38.6 |
| 4.333 | 43.0 |

Least Squares Regression

Horizontal Load = - 0.635 + 0.1157 x (Division)

Time: 11:40 Model: Base beam, short midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.899 | 9.0 | 0.4067 |
| 7.899 | 15.5 | 1.1589 |
| 12.899 | 22.0 | 1.9112 |
| 17.899 | 28.0 | 2.6056 |
| 22.899 | 35.0 | 3.4158 |
| 27.899 | 41.0 | 4.1102 |
| 32.899 | 46.5 | 4.7467 |

Least Squares Regression

Horizontal Load = 0.0105 + 0.1459 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 15, 1989

Ice Thickness: 30.1mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.3 |
| 0.833 | 12.8 |
| 1.333 | 17.0 |
| 1.833 | 21.4 |
| 2.333 | 25.5 |
| 2.833 | 30.0 |
| 3.333 | 34.2 |
| 3.833 | 38.6 |
| 4.333 | 43.0 |

Least Squares Regression

Horizontal Load = - 0.635 + 0.1157 x (Division)

Time: 12:20 Model: Base beam, long midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.819 | 8.5 | 0.3488 |
| 7.819 | 15.2 | 1.1242 |
| 12.819 | 21.0 | 1.8533 |
| 17.819 | 27.5 | 2.5478 |
| 22.819 | 33.0 | 3.1843 |
| 27.819 | 39.0 | 3.8787 |
| 32.819 | 44.5 | 4.5152 |

Least Squares Regression

Horizontal Load = 0.0764 + 0.1363 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 15, 1989

Ice Thickness: 30.1mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 8.3 |
| 0.833 | 12.8 |
| 1.333 | 17.0 |
| 1.833 | 21.4 |
| 2.333 | 25.5 |
| 2.833 | 30.0 |
| 3.333 | 34.2 |
| 3.833 | 38.6 |
| 4.333 | 43.0 |

Least Squares Regression

Horizontal Load = - 0.635 + 0.1157 x (Division)

Time: 12:30 Model: Base beam, long midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.785 | 8.5 | 0.3488 |
| 7.785 | 14.5 | 1.0432 |
| 12.785 | 20.5 | 1.7376 |
| 17.785 | 26.0 | 2.3742 |
| 22.785 | 32.5 | 3.1264 |
| 27.785 | 38.0 | 3.7630 |
| 32.785 | 45.0 | 4.5731 |

Least Squares Regression

Horizontal Load = -0.0537 + 0.1393 x (vertical load)

# FRICTION TEST DATA SHEET

Date: June 16, 1989

Ice Thickness: 29.9mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division | |
|---|---|---|
| 0.333 | 5.0 | |
| 0.833 | 9.5 | |
| 1.333 | 14.0 | |
| 1.833 | 18.0 | |
| 2.333 | 22.5 | |
| 2.833 | 26.8 | |
| 3.333 | 31.0 | |
| 3.833 | | 35.5 |
| 4.333 | 39.8 | |

Least Squares Regression

Horizontal Load = - 0.2578 + 0.1154 x (vertical load)

Time: 10:30 Model: Base beam, long midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.841 | 5.0 | 0.3191 |
| 7.841 | 9.5 | 0.8383 |
| 12.841 | 13.5 | 1.2998 |
| 17.841 | 17.2 | 1.7266 |
| 22.841 | 21.5 | 2.2228 |
| 27.841 | 25.5 | 2.6843 |
| 32.841 | 29.2 | 3.1111 |

Least Squares Regression

Horizontal Load = 0.0876 + 0.0928 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 16, 1989

Ice Thickness: 29.9mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 5.0 |
| 0.833 | 9.5 |
| 1.333 | 14.0 |
| 1.833 | 18.0 |
| 2.333 | 22.5 |
| 2.833 | 26.8 |
| 3.333 | 31.0 |
| 3.833 | 35.5 |
| 4.333 | 39.8 |

Least Squares Regression

Horizontal Load = - 0.2578 + 0.1154 x (vertical load)

Time: 10:37 Model: Base beam, long midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.973 | 4.5 | 0.2614 |
| 7.973 | 9.5 | 0.8383 |
| 12.973 | 13.7 | 1.3228 |
| 17.973 | 17.0 | 1.7036 |
| 22.973 | 21.7 | 2.2458 |
| 27.973 | 26.0 | 2.7419 |
| 32.973 | 29.0 | 3.0881 |
| 37.973 | 33.2 | 3.5726 |

Least Squares Regression

Horizontal Load = 0.05969 + 0.09340 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 16, 1989

Ice Thickness: 29.9mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 5.0 |
| 0.833 | 9.5 |
| 1.333 | 14.0 |
| 1.833 | 18.0 |
| 2.333 | 22.5 |
| 2.833 | 26.8 |
| 3.333 | 31.0 |
| 3.833 | 35.5 |
| 4.333 | 39.8 |

Least Squares Regression

Horizontal Load = - 0.2578 + 0.1154 x (vertical load)

Time: 10:55 Model: Base beam, short midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.901 | 4.5 | 0.2614 |
| 7.901 | 9.5 | 0.8036 |
| 12.901 | 13.7 | 1.2998 |
| 17.901 | 18.0 | 1.8189 |
| 22.901 | 22.0 | 2.2804 |
| 27.901 | 27.5 | 2.9150 |
| 32.901 | 32.0 | 3.4342 |
| 37.901 | 36.8 | 3.9880 |

Least Squares Regression

Horizontal Load = - 0.0636 + 0.10606 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 16, 1989

Ice Thickness: 29.9mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 5.0 |
| 0.833 | 9.5 |
| 1.333 | 14.0 |
| 1.833 | 18.0 |
| 2.333 | 22.5 |
| 2.833 | 26.8 |
| 3.333 | 31.0 |
| 3.833 | 35.5 |
| 4.333 | 39.8 |

Least Squares Regression

Horizontal Load = - 0.2578 + 0.1154 x (Vertical Load)

Time: 11:45 Model: Base beam, short midsection

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.869 | 5.0 | 0.3191 |
| 7.869 | 9.5 | 0.8282 |
| 12.869 | 14.0 | 1.3574 |
| 17.869 | 18.0 | 1.8189 |
| 22.869 | 23.0 | 2.3958 |
| 27.869 | 28.0 | 2.9727 |
| 32.869 | 32.5 | 3.4919 |
| 37.869 | 37.5 | 4.0688 |

Least Squares Regression

Horizontal Load = - 0.02156 + 0.1070 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 16, 1989

Ice Thickness: 29.9mm

Ice Strength: 25 kPa

Calibration:

| Horizontal (kg) | Division |
|---|---|
| 0.333 | 5.0 |
| 0.833 | 9.5 |
| 1.333 | 14.0 |
| 1.833 | 18.0 |
| 2.333 | 22.5 |
| 2.833 | 26.8 |
| 3.333 | 31.0 |
| 3.833 | 35.5 |
| 4.333 | 39.8 |

Least Squares Regression

Horizontal Load = - 0.2578 + 0.1154 x (Vertical Load)

Time: 12:45 Model: Increased beam

Friction Test:

| Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|
| 2.910 | 4.0 | 0.2037 |
| 7.910 | 7.5 | 0.6075 |
| 12.910 | 11.0 | 1.0113 |
| 17.910 | 14.0 | 1.3574 |
| 22.910 | 17.0 | 1.7036 |
| 27.910 | 20.5 | 2.1074 |
| 32.910 | 23.5 | 2.4535 |
| 37.910 | 26.5 | 2.7996 |

Least Squares Regression

Horizontal Load = 0.02231 + 0.0739 x (vertical load)

## FRICTION TEST DATA SHEET

Date: June 16, 1989

Ice Thickness: 29.9mm

Ice Strength: 25 kPa

| Calibration: | Horizontal (kg) | Division |
|---|---|---|
| | 0.333 | 5.0 |
| | 0.833 | 9.5 |
| | 1.333 | 14.0 |
| | 1.833 | 18.0 |
| | 2.333 | 22.5 |
| | 2.833 | 26.8 |
| | 3.333 | 31.0 |
| | 3.833 | 35.5 |
| | 4.333 | 39.8 |

Least Squares Regression

Horizontal Load = - 0.2578 + 0.1154 x (Vertical Load)

Time: 13:00 Model: Increased beam

| Friction Test: | Vertical Load (kg) | Division | Horizontal Load (kg) |
|---|---|---|---|
| | 2.845 | 4.0 | 0.2037 |
| | 7.845 | 7.5 | 0.6075 |
| | 12.845 | 10.5 | 0.9536 |
| | 17.845 | 13.5 | 1.2998 |
| | 22.845 | 17.0 | 1.7036 |
| | 27.845 | 20.0 | 2.0497 |
| | 32.845 | 23.5 | 2.4535 |
| | 37.845 | 26.0 | 2.7419 |

Least Squares Regression

Horizontal Load = 0.01505 + 0.07307 x (vertical load)

# APPENDIX B3

# ICE BREAKING MODEL TEST RESULTS

## B3.1 Summary of Test Results

The following tables present the complete set of data from the Midbody Phase II Model Test Program.

## B3.2 Icebreaking and Ice Clearing Coefficients

Table B3.2.1 presents the calculation of the icebreaking coefficient, and Table B3.2.2 presents the calculation of ice clearing coefficient, table B3.2.3 presents the nondimensional clearing and breaking coefficients and indices. These are described in the following text.

Table B3.2.1

a) Column 1: Model test identifier, eg. MB03/D/I/30 Melville Bow test #3 /Decreased beam / Intermediate length / 30mm ice.

b) Column 2: Model speed

c) Column 3: Measured ice thickness

d) Column 4: Measured ice flexural strength

e) Column 5: Measured ice density

f) Column 6: Measured total resistance during the test

g) Column 7: Calculated Clearing resistance. The clearing resistance is calculated from table B3.2.2 using the calculated clearing coefficient and index for each model presented in table B3.2.3.

For Example;

$$\text{Calculated Clearing Resistance} = AC^{*}(\rho BhV^{2})^{*}((\ V/(gh)^{1/4}))^{n2}$$

h) Column 8: Frictional resistance. The frictional resistance is calculated as a function of the Reynolds number and model length based on the ITTC line.

i) Column 9: Breaking Resistance. The total measured resistance, column 6, minus the calculated Ice Clearing resistance, column 7, and frictional resistance, column 8.

j) Column 10: Non-Dimensional Breaking coefficient. Calculated with the algorithm; $R_b / (\rho B h V^2)$

k) Column 11: Ice Strength Number.
Calculated with the algorithm; $(V/(\sigma/\rho)^{1/4})$

l) Column 12 Calculated Breaking Resistance. The breaking resistance calculated from the coefficient and index for each model, presented in table B3.2.3.

For example;

Calculated Breaking Resistance = $AB*(\rho B h V^2)*((V/(\sigma/\rho)^{1/4}))^{n1}$

n) Column 13 Calculated Total Resistance. The calculated breaking resistance, column 12, plus the calculated clearing resistance, column 7, plus the frictional resistance, column 8.

Table B3.2.2

a) Column 1: Model test identifier, eg. MB03/D/I/30 Melville Bow test #3 /Decreased beam / Intermediate length / 30mm ice.

b) Column 2: Model speed

c) Column 3: Measured ice thickness

d) Column 4: Estimated ice flexural strength during presawn tests

e) Column 5: Estimated ice density

f) Column 6: Presawn resistance recorded during the tests.

g) Column 7: Frictional resistance. The frictional resistance is calculated as a function of the Reynolds number and model length based on the ITTC line.

h) Column 8: Clearing Resistance. The total presawn resistance, column 6, minus the frictional resistance, column 7.

i) Column 9: Non-dimensional clearing resistance.
Defined as; $R_c / (\rho B h V^2)$

j) Column 10: Thickness Froude Number. Defined as: $(V/(gh)^{1/4})$

k) Column 11: Model Friction coefficient.

TABLE B3.2.1
BEAM TEST RESULTS
CALCULATION OF NONDIMENSIONAL BREAKING COEFFICIENT

| COLUMN # / DESCRIPTION OF MODEL | 2 SPEED (m/s) | 3 MEAS. ICE THICK (mm) | 4 MEAS. FLEXURAL STRENGTH (kPa) | 5 MEAS. ICE DENSITY (kg/m^3) | 6 MEAS TOTAL RES. (N) | 7 CALC. CLEARING RES (N) | 8 FRICT RES. (N) | 9 BREAKING RES. (N) | 10 NON-DIM BREAKING COEFF. | 11 ICE STRENGTH NUMBER | 12 CALC. BKING RES. (N) | 13 CALC TOTAL RES. (N) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MB01/O/O/30 | 0.166 | 29.50 | 21.00 | 944.91 | 59.00 | 18.01 | 0.57 | 40.42 | 69.06 | 1.1135 | 31.96 | 50.54 |
| MB01/O/O/30 | 0.307 | 29.60 | 24.00 | 944.24 | 73.00 | 23.50 | 1.71 | 47.79 | 23.81 | 1.9256 | 45.65 | 70.87 |
| MB01/O/O/30 | 0.448 | 30.00 | 16.67 | 945.61 | 71.56 | 27.88 | 3.37 | 40.31 | 9.29 | 3.3742 | 40.25 | 71.50 |
| MB01/O/O/30 | 0.578 | 29.30 | 22.00 | 944.78 | 94.00 | 30.73 | 5.33 | 57.94 | 8.22 | 3.7878 | 54.34 | 90.40 |
| MB05/O/O/40 | 0.190 | 39.30 | 20.00 | 941.00 | 68.00 | 31.96 | 0.73 | 35.31 | 34.71 | 1.3033 | 43.19 | 75.88 |
| MB05/O/O/40 | 0.330 | 39.80 | 22.00 | 940.37 | 93.00 | 40.18 | 1.95 | 50.88 | 16.38 | 2.1575 | 58.90 | 101.02 |
| MB05/O/O/40 | 0.471 | 39.20 | 17.00 | 941.68 | 101.00 | 47.17 | 3.69 | 50.14 | 8.04 | 3.5055 | 54.46 | 105.32 |
| MB05/O/O/40 | 0.601 | 40.00 | 16.67 | 941.41 | 122.80 | 51.45 | 5.72 | 65.64 | 6.33 | 4.5164 | 60.32 | 117.49 |
| MB02/D/O/30 | 0.166 | 29.50 | 24.00 | 944.28 | 56.60 | 12.06 | 0.52 | 44.02 | 94.01 | 1.0412 | 44.48 | 57.07 |
| MB02/D/O/30 | 0.307 | 29.70 | 24.00 | 944.20 | 61.40 | 20.73 | 1.55 | 39.12 | 24.26 | 1.9256 | 36.35 | 58.63 |
| MB02/D/O/30 | 0.448 | 29.60 | 24.00 | 944.24 | 58.56 | 28.36 | 3.06 | 27.15 | 7.93 | 2.8100 | 31.87 | 63.28 |
| MB02/D/O/30 | 0.578 | 29.10 | 28.00 | 943.61 | 77.80 | 35.03 | 4.83 | 37.94 | 6.78 | 3.3554 | 34.41 | 74.28 |
| MB03/D/I/30 | 0.190 | 28.90 | 20.00 | 943.37 | 39.20 | 10.59 | 0.53 | 28.08 | 46.67 | 1.3063 | 25.26 | 36.38 |
| MB03/D/I/30 | 0.331 | 29.20 | 26.00 | 943.99 | 46.50 | 16.64 | 1.41 | 28.44 | 15.44 | 1.9945 | 33.39 | 51.45 |
| MB03/D/I/30 | 0.472 | 29.20 | 26.00 | 943.99 | 56.60 | 22.31 | 2.67 | 31.62 | 8.44 | 2.8441 | 33.58 | 58.56 |
| MB03/D/I/30 | 0.601 | 30.00 | 27.00 | 943.44 | 69.73 | 25.30 | 4.11 | 40.31 | 6.46 | 3.5526 | 35.95 | 65.37 |
| MB04/D/S/30 | 0.190 | 29.90 | 25.00 | 943.90 | 35.70 | 12.50 | 0.43 | 22.76 | 36.63 | 1.1675 | 22.01 | 34.95 |
| MB04/D/S/30 | 0.331 | 29.70 | 30.00 | 942.94 | 45.50 | 16.82 | 1.16 | 27.53 | 14.71 | 1.8557 | 29.53 | 47.51 |
| MB04/D/S/30 | 0.472 | 30.50 | 27.00 | 943.23 | 55.10 | 21.58 | 2.18 | 31.34 | 8.02 | 2.7898 | 30.29 | 54.04 |
| MB04/D/S/30 | 0.601 | 29.80 | 29.00 | 943.10 | 60.50 | 23.56 | 3.36 | 33.58 | 5.42 | 3.4273 | 33.50 | 60.42 |
| MB06/O/L/30 | 0.190 | 29.10 | 24.00 | 944.45 | 50.00 | 21.71 | 0.90 | 27.39 | 36.23 | 1.1919 | 27.54 | 50.15 |
| MB06/O/L/30 | 0.331 | 29.30 | 25.00 | 944.15 | 71.00 | 30.57 | 2.44 | 37.99 | 16.45 | 2.0341 | 37.85 | 70.86 |
| MB06/O/L/30 | 0.472 | 28.80 | 25.00 | 944.36 | 90.16 | 38.32 | 4.62 | 47.22 | 10.23 | 2.9010 | 45.69 | 88.63 |
| MB06/O/L/30 | 0.601 | 28.20 | 29.00 | 943.78 | 104.00 | 43.15 | 7.14 | 54.71 | 7.47 | 3.4285 | 55.97 | 105.26 |
| MB07/I/O/30 | 0.190 | 29.90 | 24.00 | 944.11 | 61.00 | 22.17 | 0.80 | 38.03 | 40.83 | 1.1917 | 37.31 | 60.28 |
| MB07/I/O/30 | 0.331 | 30.40 | 24.00 | 943.90 | 71.00 | 33.72 | 2.15 | 35.13 | 12.23 | 2.0758 | 38.11 | 73.98 |
| MB07/I/O/30 | 0.472 | 30.20 | 22.00 | 944.41 | 87.00 | 43.63 | 4.07 | 39.30 | 6.77 | 3.0925 | 34.81 | 82.51 |
| MB07/I/O/30 | 0.602 | 29.90 | 22.00 | 944.53 | 90.00 | 51.16 | 6.29 | 32.56 | 3.49 | 3.9380 | 34.54 | 91.98 |
| MB08/I/S/30 | 0.190 | 30.00 | 24.00 | 944.07 | 60.50 | 22.44 | 0.62 | 37.44 | 40.07 | 1.1917 | 36.58 | 59.63 |
| MB08/I/S/30 | 0.331 | 30.20 | 23.00 | 944.20 | 65.10 | 33.90 | 1.66 | 29.54 | 10.35 | 2.1208 | 31.97 | 67.53 |
| MB08/I/S/30 | 0.472 | 30.00 | 24.00 | 944.07 | 81.60 | 44.69 | 3.13 | 33.77 | 5.86 | 2.9603 | 31.30 | 79.12 |
| MB08/I/S/30 | 0.601 | 29.70 | 24.00 | 944.20 | 85.60 | 51.65 | 4.84 | 29.12 | 3.15 | 3.7696 | 29.73 | 86.21 |

TABLE B3.2.2
BEAM TEST RESULTS
CALCULATION OF NONDIMENSIONAL CLEARING COEFFICIENT

| COLUMN # DESCRIPTION OF MODEL | 2 SPEED (m/s) | 3 MEAS. ICE THICK (mm) | 4 EST. ICE STRENGTH (kPa) | 5 EST ICE DENSITY (kg/m^3) | 6 P.SAWN RESIST. (N) | 7 FRICT RES. (N) | 8 CLEARING RES. (N) | 9 NON-DIM CLEARING COEFF | 10 THICKNESS FROUDE NUMBER | 11 FRICT. COEFF |
|---|---|---|---|---|---|---|---|---|---|---|
| MB01/O/O/30 | 0.166 | 29.60 | 16.30 | 945.86 | 19.00 | 0.57 | 18.43 | 31.34 | 0.31 | 0.10 |
| MB01/O/O/30 | 0.307 | 29.40 | 16.30 | 945.94 | 22.00 | 1.71 | 20.29 | 10.16 | 0.57 | 0.10 |
| MB01/O/O/30 | 0.448 | 29.40 | 16.30 | 945.94 | 32.00 | 3.37 | 28.63 | 6.73 | 0.83 | 0.10 |
| MB01/O/O/30 | 0.578 | 29.10 | 16.30 | 946.07 | 38.00 | 5.33 | 32.67 | 4.66 | 1.08 | 0.10 |
| MB05/O/O/40 | 0.190 | 39.60 | 13.00 | 942.35 | 35.00 | 0.73 | 34.27 | 33.59 | 0.30 | 0.10 |
| MB05/O/O/40 | 0.331 | 39.10 | 13.00 | 942.56 | 41.00 | 1.95 | 39.05 | 12.69 | 0.53 | 0.10 |
| MB05/O/O/40 | 0.472 | 39.10 | 13.00 | 942.56 | 49.00 | 3.69 | 45.31 | 7.34 | 0.76 | 0.10 |
| MB05/O/O/40 | 0.601 | 38.60 | 13.00 | 942.77 | 59.00 | 5.72 | 53.28 | 5.32 | 0.98 | 0.10 |
| MB02/D/O/30 | 0.166 | 29.40 | 13.70 | 946.49 | 13.50 | 0.52 | 12.98 | 27.75 | 0.31 | 0.12 |
| MB02/D/O/30 | 0.307 | 30.00 | 13.70 | 946.23 | 19.98 | 1.55 | 18.43 | 11.29 | 0.57 | 0.12 |
| MB02/D/O/30 | 0.448 | 30.00 | 13.70 | 946.23 | 29.64 | 3.06 | 26.58 | 7.65 | 0.83 | 0.12 |
| MB02/D/O/30 | 0.578 | 30.00 | 13.70 | 946.23 | 43.89 | 4.83 | 39.06 | 6.75 | 1.07 | 0.12 |
| MB03/D/I/30 | 0.190 | 27.80 | 10.60 | 947.81 | 12.00 | 0.53 | 11.47 | 19.77 | 0.36 | 0.12 |
| MB03/D/I/30 | 0.331 | 28.60 | 10.60 | 947.47 | 16.00 | 1.41 | 14.59 | 8.05 | 0.63 | 0.12 |
| MB03/D/I/30 | 0.472 | 29.20 | 10.60 | 947.22 | 24.00 | 2.67 | 21.33 | 5.68 | 0.88 | 0.12 |
| MB03/D/I/30 | 0.601 | 28.30 | 10.60 | 947.60 | 32.00 | 4.11 | 27.89 | 4.72 | 1.14 | 0.12 |
| MB04/D/S/30 | 0.190 | 30.00 | 20.50 | 944.81 | 13.90 | 0.43 | 13.47 | 21.58 | 0.35 | 0.12 |
| MB04/D/S/30 | 0.331 | 29.60 | 20.50 | 944.97 | 16.10 | 1.16 | 14.94 | 7.99 | 0.61 | 0.12 |
| MB04/D/S/30 | 0.472 | 30.40 | 20.50 | 944.64 | 22.50 | 2.18 | 20.32 | 5.21 | 0.86 | 0.12 |
| MB04/D/S/30 | 0.601 | 29.50 | 20.50 | 945.02 | 29.50 | 3.36 | 26.14 | 4.26 | 1.12 | 0.12 |
| MB06/O/L/30 | 0.190 | 29.10 | 11.90 | 946.99 | 23.00 | 0.90 | 22.10 | 29.15 | 0.36 | 0.06 |
| MB06/O/L/30 | 0.331 | 28.90 | 11.90 | 947.07 | 33.00 | 2.44 | 30.56 | 13.37 | 0.62 | 0.06 |
| MB06/O/L/30 | 0.472 | 28.90 | 11.90 | 947.07 | 40.00 | 4.62 | 35.38 | 7.61 | 0.89 | 0.06 |
| MB06/O/L/30 | 0.601 | 27.90 | 11.90 | 947.49 | 52.00 | 7.14 | 44.86 | 6.17 | 1.15 | 0.06 |
| MB07/I/O/30 | 0.190 | 29.70 | 17.30 | 945.60 | 23.00 | 0.80 | 22.20 | 23.96 | 0.3. | 0.07 |
| MB07/I/O/30 | 0.331 | 30.00 | 17.30 | 945.48 | 36.00 | 2.15 | 33.85 | 11.92 | 0.61 | 0.07 |
| MB07/I/O/30 | 0.472 | 30.00 | 17.30 | 945.48 | 47.00 | 4.07 | 42.93 | 7.43 | 0.87 | 0.07 |
| MB07/I/O/30 | 0.601 | 29.70 | 17.30 | 945.60 | 58.00 | 6.29 | 51.71 | 5.58 | 1.11 | 0.07 |
| MB08/I/S/30 | 0.190 | 29.70 | 11.10 | 946.91 | 23.50 | 0.62 | 22.88 | 24.66 | 0.35 | 0.07 |
| MB08/I/S/30 | 0.331 | 29.80 | 11.10 | 946.86 | 34.56 | 1.66 | 32.90 | 11.64 | 0.61 | 0.07 |
| MB08/I/S/30 | 0.472 | 30.10 | 11.10 | 946.74 | 47.00 | 3.13 | 43.87 | 7.56 | 0.87 | 0.07 |
| MB08/I/S/30 | 0.601 | 29.50 | 11.10 | 946.99 | 58.00 | 4.84 | 53.16 | 5.76 | 1.12 | 0.07 |

TABLE B3.2.3
BEAM TEST RESULTS
NONDIMENSIONAL COEFFICIENTS AND INDICES

| COLUMN # | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| DESCRIPTION OF MODEL | MODEL BEAM [ = ] | CLEARING INDEX n2 | CLEARING COEFF. AC | BREAKING INDEX n1 | BREAKING COEFF. AB |
| MB01/O/O/30 | | | | | |
| MB05/O/O/40 | 0.762 | (1.55) | 4.95 | (1.60) | 64.85 |
| MB02/D/O/30 | 0.610 | (1.17) | 6.52 | (2.34) | 104.43 |
| MB03/D/I/30 | 0.610 | (1.27) | 5.06 | (1.98) | 71.33 |
| MB04/D/S/30 | 0.610 | (1.43) | 4.49 | (1.74) | 46.41 |
| MB06/O/L/30 | 0.762 | (1.36) | 7.00 | (1.47) | 47.02 |
| MB07/I/O/30 | 0.914 | (1.27) | 6.33 | (1.99) | 56.81 |
| MB08/I/S/30 | 0.914 | (1.27) | 6.45 | (2.17) | 57.28 |

# APPENDIX B4

# ICE SHEET DATA

## TABLE B4.1

## ICE SHEET DATA

| Date | Sheet # | Ice Thickness (mm) | # Samples | Ice Flexural | # Samples |
|---|---|---|---|---|---|
| 6 Jun 89 | 1 | 29.3 +/- 0.7 | 66 | 23 +/- 3 | 25 |
| 7 Jun 89 | 2 | 29.5 +/- 0.7 | 66 | 25 +/- 3 | 25 |
| 8 Jun 89 | 3 | 28.9 +/- 0.7 | 66 | 25 +/- 4 | 24 |
| 9 Jun 89 | 4 | 30.0 +/- 0.9 | 66 | 28 +/- 3 | 26 |
| 13 Jun 89 | 5 | 39.1 +/- 1.0 | 66 | 20 +/- 3 | 22 |
| 14 Jun 89 | 6 | 28.7 +/- 0.7 | 66 | 26 +/- 3 | 26 |
| 15 Jun 89 | 7 | 30.1 +/- 0.6 | 66 | 25 +/- 4 | 24 |
| 16 Jun 89 | 8 | 29.9 +/- 0.7 | 66 | 25 +/- 3 | 24 |

# APPENDIX C

# DETAILED TEST ANALYSIS

## C.1 Detailed Model Test Analysis

Three model configurations were tested, the model of the ARCTIC, at a scale of 1:30, referred to as the "Base Beam, Base Midbody". This model was also tested with an additional midbody section and is referred to as the "Base Beam, Long Midbody". The second model was an copy of the base model with a 20% wider beam. This was tested with the same length as the "Base Beam, Base Midbody" and is referred to as the "Increased Beam, Base Midbody" and without a midbody section referred to as the "Increased Beam, Short Midbody". The third configuration was a copy of the base model with a 20% narrower beam. This was tested with length equal to the "Base Beam, Base Midbody" referred to as the "Decreased Beam, Base Midbody" and two shorter lengths referred to as "Decreased Beam, Intermediate Midbody" and "Decreased Beam, Short Midbody".

The model test results from the BEAM test program, presented as table C.1, were reviewed with respect to consistency with each other and with other test programs that have been conducted by Melville on similar models. The results of this analysis are presented in the following notes;

It should be noted that a standard procedure for correcting the resistance for thickness and strength has been used initially in the following analysis. Ice strength has been corrected to the target ice strength using a linear interpolation between the resistance measured during the presawn ice tests and assigned a value of zero strength and the resistance measured during the conventional level ice tests with their associated ice strength. Ice thickness at each speed has been corrected using a linear interpolation between the 30 and 40 mm ice sheets tested in this program.

a) Friction Coefficient

The model tests were conducted at a target friction coefficient of 0.06 to correlate with earlier model test programs. To achieve a consistent surface finish the new models that were constructed and existing models were repainted together using the same paint mix and procedure. The normal procedure for measuring the friction coefficient is to paint a test panel and use the Friction Jig, described in the model test report. Two panels were painted but did not appear to adequately represent the surface on the model, as a result one board was repainted and both boards tested in the jig. The results of the tests were two friction coefficients, 0.069 for the original painting and 0.093 for the second painting. These results were not considered to be sufficiently close and it was elected to test the actual model parts. Due to the configuration of the Friction Jig it was only possible to test the midbody

sections. The results of these tests were, for the existing beam 0.1, for the wide beam midbody, 0.068 and for the narrow beam section, 0.12.

These values are generally larger than the equivalent values attributed to the plates. Tests were conducted with the panels supported on the model to test the panels in the same configuration as the model segments. The 0.069 plate was tested on the model, using the different set up. The result of these tests was a friction coefficient of 0.065. This would indicate that the different set up was not responsible.

Since the friction testing was not conclusive it was elected to use the model tests that were conducted as part of the MIDBODY tests and repeated in the BEAM tests for a friction correlation. As discussed below this resulted in a friction coefficient of 0.1 which is close to the friction coefficient recorded on the original panel, painted with the models.

The friction coefficient used on the other model configurations were taken from the friction tests and these were, for the Increased Beam, 0.068 and, for the Decreased Beam, 0.12.

The relationship between friction coefficient and resistance has been developed as part of the MIDBODY and FRICTION test programs. These programs included tests in 50 mm ice with the base ARCTIC model with the Melville Bow, and tests in 30 mm ice with the short model of the ARCTIC with the Melville bow. Based on the correlation described below and the tests conducted to date it was elected to correct the BEAM tests using the 50 mm ice resistance vs friction coefficient relationship for the 40 mm ice sheet tests and the 30 mm short ship resistance vs friction coefficient relationship for the 30 mm ice tests.

b) Model of Existing Ship Configuration

As discussed above two ice sheets were used to compare the results of the existing Arctic model as tested during the BEAM program and MIDBODY program. The ice sheets tested were 30 and 40 mm representing 0.9 and 1.2 m full scale ice respectively. Figure C.1 presents the data from the two ice sheets corrected to target values of thickness and strength using the standard procedure described above. The ice strength was corrected to 16.67 kPa using a linear interpolation between the presawn resistance and the measured resistance at the test strength. The ice thickness was corrected to 30 and 40 mm using a linear interpolation between the strength corrected resistance in the 30 and 40 mm ice sheets at the same speed.

It can be seen from figure C.1 that the 30 mm ice sheet is reasonably consistent, but the 40 mm sheet has a very irregular data point at either 0.448 or .578 m/sec.

The same model and ice sheet parameters were tested in the MIDBODY and FRICTION test programs. Figure C.2 compares the data between the test programs. The only difference between these tests is that the friction coefficient for the MIDBODY and FRICTION tests was 0.06 and for the BEAM tests, as discussed above, is 0.1. The FRICTION test program included a range of friction coefficients from which friction correlations have been extracted for correlating other test results for different friction values. Figure C.3 illustrates the BEAM tests, corrected to 0.06. It can be seen from this figure that the 30 and 40 mm BEAM test results compare well with the FRICTION and MIDBODY results. However the high speed, 0.601 m/sec, 40 mm result is low and the 30 mm, 0.578 m/sec point, appears to be high. These data points were reviewed in more detail.

The ice strength for the 40 mm sheet ranged from 20 to 23 kPa for the two lowest and the highest speed and 17 kPa for the 0.471 m/sec speed. Figure C.4 illustrates the resistance vs ice strength for the data and it can be clearly seen that either the 0.471 or 0.601 m/sec data point and its associated strength is not consistent with the remainder of the data. Generally the rate of change of resistance with strength will uniformly increase with speed.

The same type of problem may be observed in the 30 mm ice sheet. Figure C.5 illustrates the resistance vs ice strength and it may be seen that the 0.448 m/sec data point has almost the same value of resistance as the 0.307 m/sec point with a much lower rate of change of resistance with ice strength. In comparison the 0.578 m/sec data point is high. Many previous tests have shown that the rate of change of ice resistance with strength increases with speed and this is not the case in figure C.5.

The ice strength testing methods adopted at IMD are limited in that they are very local in nature and in some cases may not be considered representative of the remaining ice sheet. The data presented in figures C.4 and C.5 tend to indicate that this may be the case and that the manual tests may have been conducted in an ice strength that was local in nature and not representative of the ice in which the model was tested. It was therefore elected to modify the high speed data point in the 40 mm ice sheet to more closely correlate with the previous MIDBODY and FRICTION data. This point was corrected to a value of 85 N at the target friction coefficient, thickness and strength based on the combined results from the MIDBODY and FRICTION test programs. A

review of the 30 mm data points did not reveal any inconsistencies and was not modified. The modified data set is presented in figure C.6

A second ice sheet was tested as part of the BEAM program that had been tested in the MIDBODY program. This as the model with the existing beam and long midbody. Figure C.7 illustrates the test results from this configuration. Clearly the correlation is good with the exception of the high speed data point. This represents the same problem identified with the existing ship model, discussed above, and partly confirms the conclusion that the manual tests for ice strength are conducted in a local "hard" area of ice. Figure C.8 presents the resistance vs strength curve for this data and highlights the inconsistency. The high speed data point was modified to a value of 104 N at target thickness and strength based on a constant rate of change of resistance and strength from the 0.471 m/sec data point. Following correction, this resulted in a resistance of 71.55 as seen on figure C.9.

The tests may also be compared on a plot of Resistance vs ice thickness, as shown in figure C.10. This plot confirms the close correlation between the BEAM, MIDBODY and FRICTION test programs.

It may be noted that the MIDBODY data points where associated with a series of irregular ice sheet strength values that required detailed analysis. During that analysis a series of procedures were adopted that involved the adjustment of the measured resistance based on relationships between resistance, strength, speed and thickness. Specifically the MIDBODY results from the 40 mm ice sheet were significantly adjusted to reflect more consistent trends of thickness and speed relationships that had been demonstrated in previous test programs. Other changes were made to the low speed, 0.188 m/sec data point in the 30 mm ice sheet. Reviewing these corrections with the BEAM tests resulted in a general confirmation of all the corrections. The data presented in figure C.10 is the corrected data from the BEAM, MIDBODY and FRICTION test programs that is used in the subsequent analysis.

The correlation developed from these three separate test programs further supports the basis of these correction procedures developed by Melville over the last few years.

It should be noted that the following analysis has been completed prior to any correction for friction.

c) Decreased Beam with Original, Intermediate and Short Midbody.

The corrected data points for the three Decreased Beam models are shown in figure C.11. The previous MIDBODY tests resulted in a low influence of length on resistance.

However, it was observed that during the Existing Length model tests the model was not lined up correctly and crushing took place on the port side of the model for the three higher speeds. This may be clearly seen by comparing figure C.12, which presents the resistance vs strength curve for this test, with figures C.13 and C.14 which present the same data for the Intermediate and Short models. Based on this observation it was elected to correct the presawn data for the Original length model. The correction was developed by extrapolating the presawn resistance measured from the Intermediate and Short Midbodies to the presawn resistance of the Base Midbody using the model lengths at each respective speed. This correction will clearly only influence the strength correction to each data point.

This second data point which is not consistent with the general trend is the Intermediate Length, 0.601 m/sec. Reviewing the resistance vs strength data in figure C.13, shows that the data point is low. The data point as adjusted using a constant rate of change of resistance and strength from the 0.472 m/sec data point.

The resultant data is shown in figure C.15 and demonstrates that, based on a more appropriate strength correction, the three midbody length models have a similar resistance across the speed range. This result confirms the MIDBODY test program.

d) Increased Beam with Original and Short Midbody

Figure C.16 presents the results from the Increased Beam series of tests. The most notable feature of this data is the downturn in resistance that occurs at the high speed 0.6 m/sec data point. Figures C.17 and C.18 present the Resistance vs Strength data for the same tests.

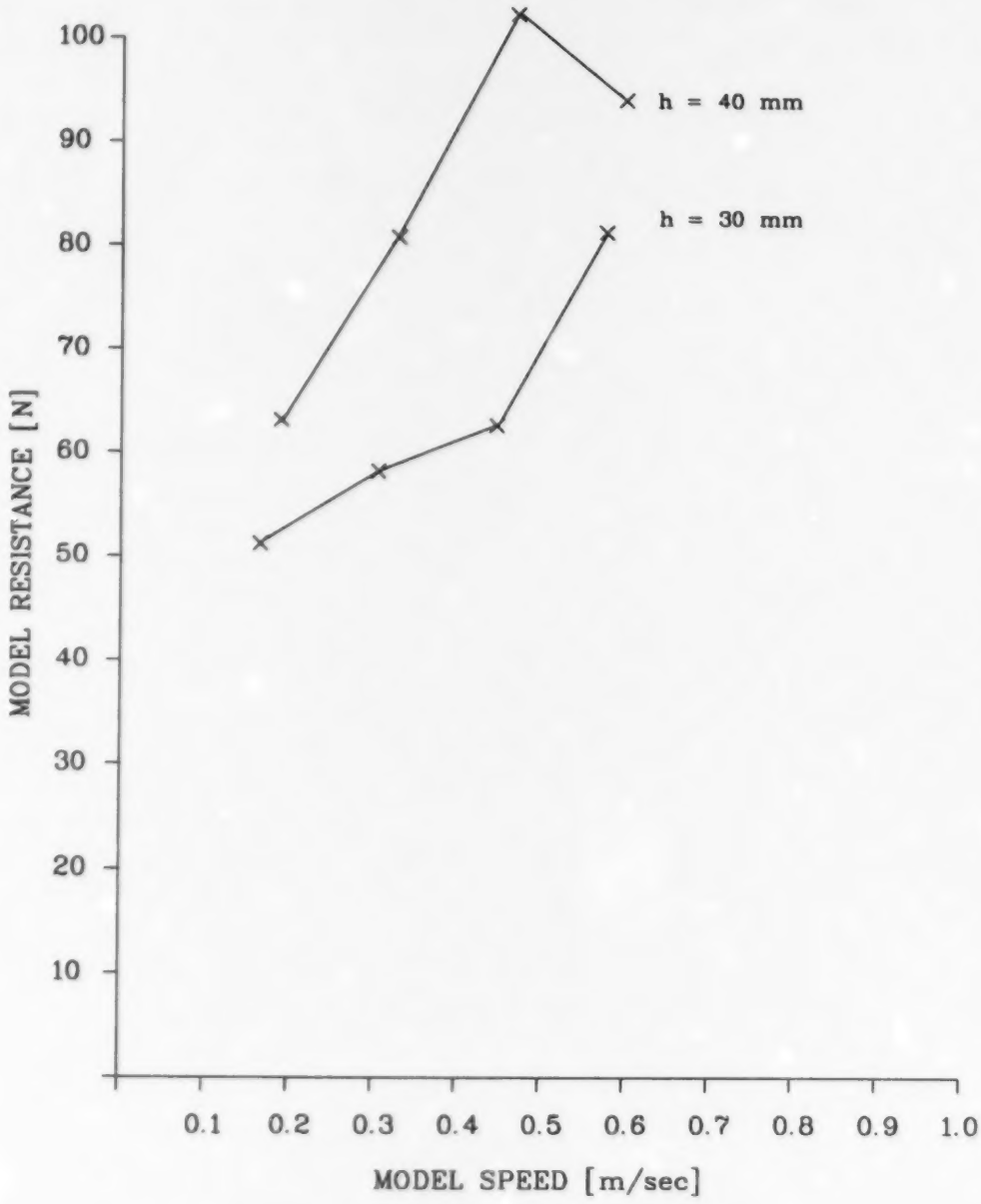
Figure C.17, the Base Midbody model has a high flexural strength allocated to the 0.6 m/sec data point. As discussed above there is always some doubt that unusually high strength values may be a local a hard spot in the ice and not representative of the ice sheet test zone. If this is the case and the 0.6 m/sec data is associated with a flexural strength equal to the next nearest test zone, 22 kPa, in lieu of 30 kPa the data becomes more consistent.

Figure C.18 presents the data from the Short Midbody model. It may be seen from the figure that the 0.331 m/sec presawn data point is too high and this is considered to be due to crushing that took place during the test. This data point was corrected using the presawn data point from the Original Midbody test, prior to any correction for strength or friction, at the same speed, 34.56 N at target ice thickness, in lieu of the 56 N. The 0.6 m/sec data point is also considered to be associated with a high flexural strength as discussed above for the Base Midbody test. This was also corrected by using the strength associated with the next nearest test zone, 24 kPa, in lieu of 28 kPa.

The resultant model resistance vs speed curves for the Increased Beam configuration are presented in Figure C.19.

FIGURE C.1

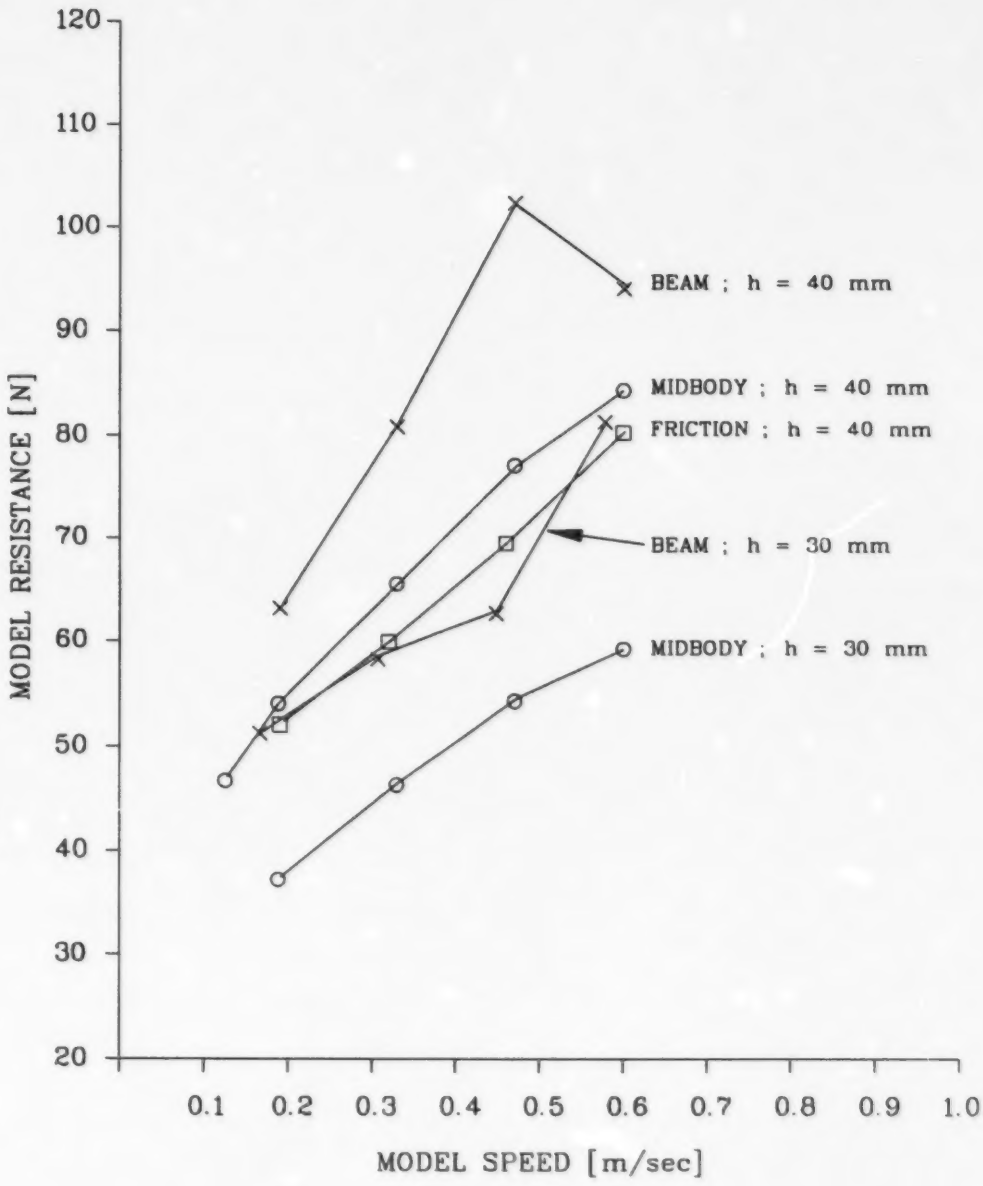
MODEL RESISTANCE vs SPEED FOR THE BASE BEAM, BASE LENGTH




Target Ice Thickness = 30 and 40 mm
Target Ice Strength = 16.67
Friction Coefficient = 0.1

FIGURE C.2

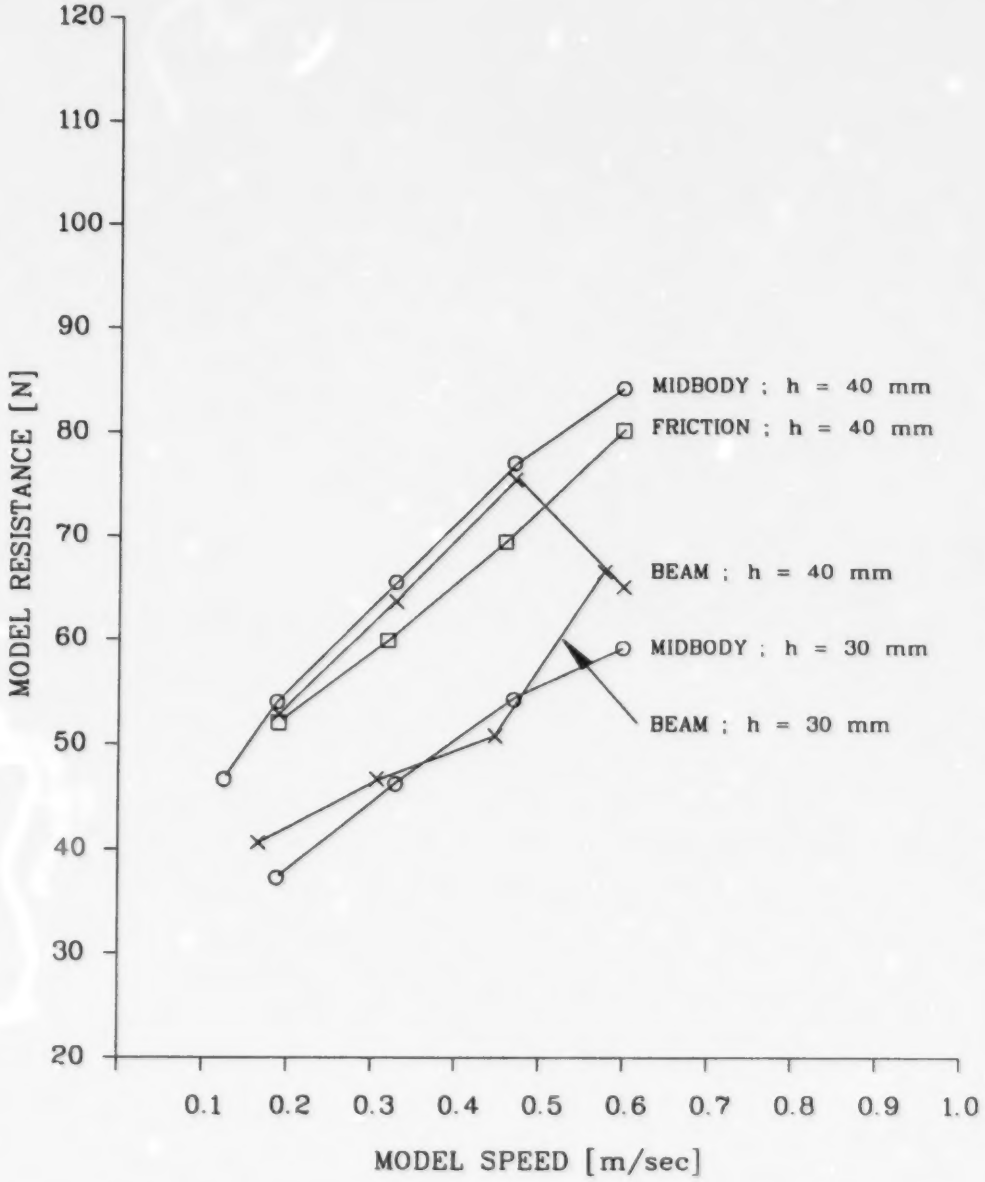
CORRECTED MODEL RESISTANCE vs SPEED FOR THE BEAM MIDBODY AND FRICTION TEST PROGRAMS




Target Ice Thickness = 30 and 40 mm
Target Ice Strength = 16.67 kPa
Friction Coefficient = 0.06 and 0.10

FIGURE C.3

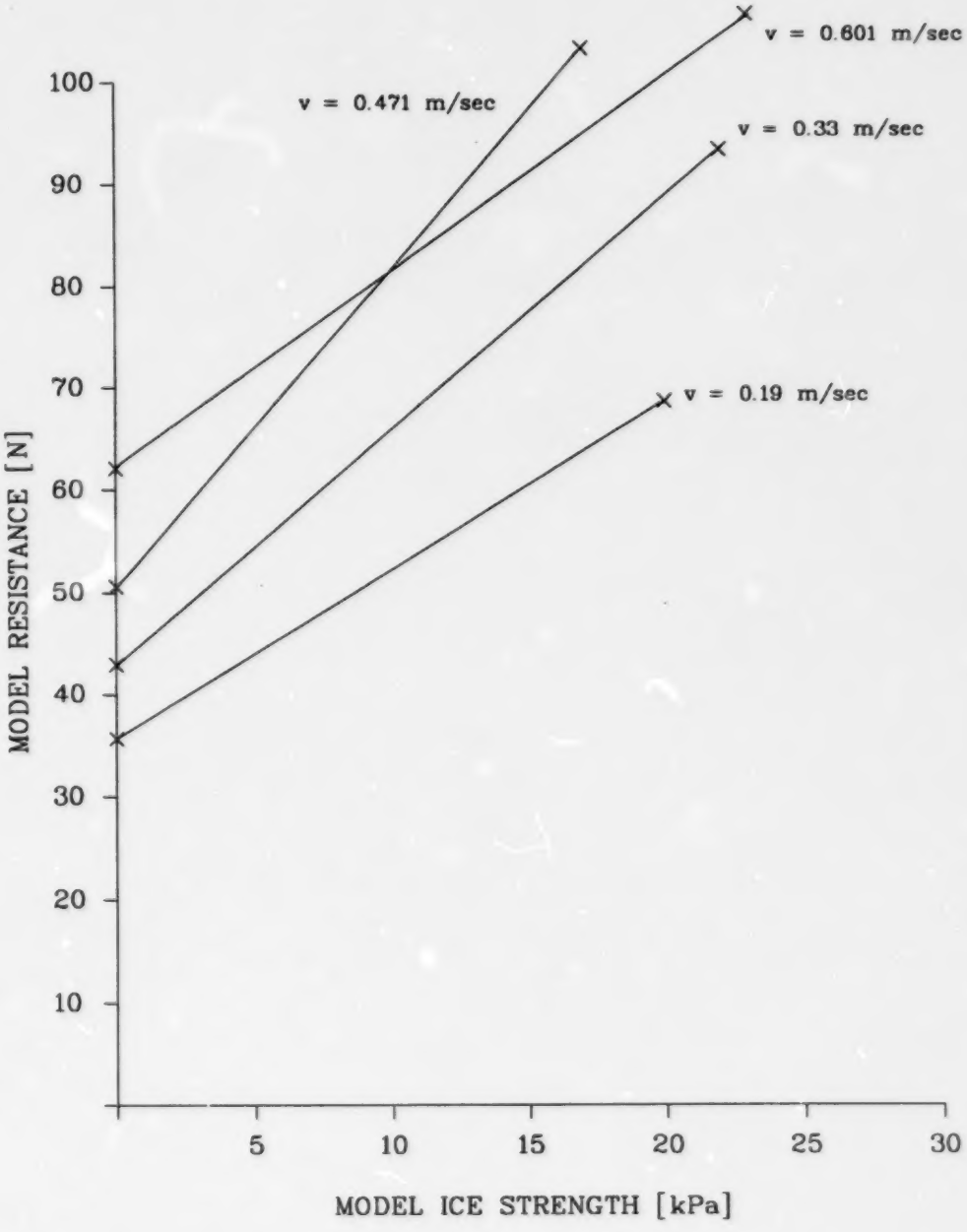
CORRECTED MODEL RESISTANCE vs SPEED FOR THE BEAM MIDBODY AND FRICTION TEST PROGRAMS




Target Ice Thickness = 30 and 40 mm
Target Ice Strength = 16.67 kPa
Target Friction Coefficient = 0.06

FIGURE C.4

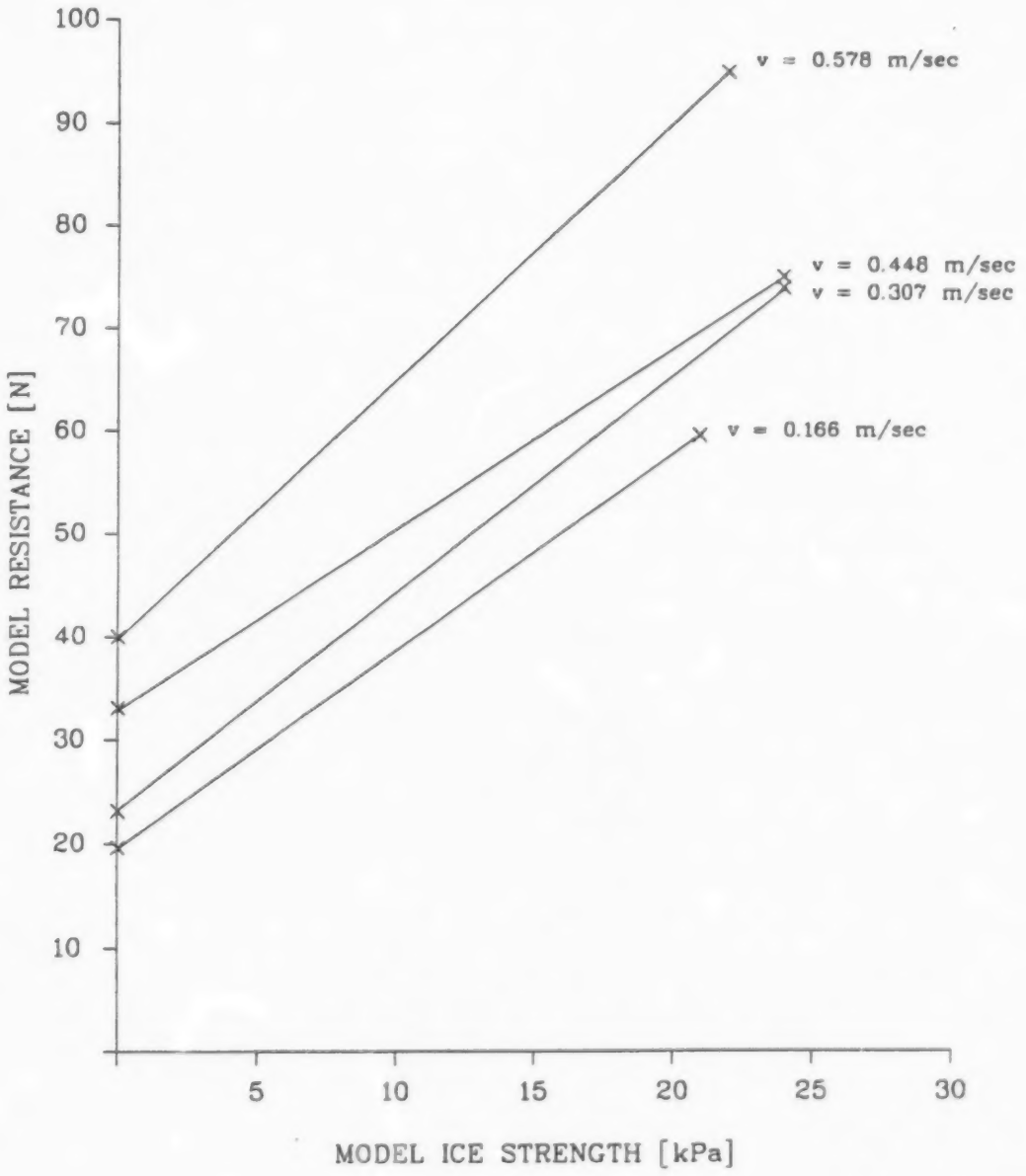
MODEL RESISTANCE vs ICE STRENGTH FOR THE BASE BEAM, BASE MIDBODY




Target Ice Thickness = 40 mm
Target Ice Strength = 25 kPa
Friction Coefficient = 0.1

FIGURE C.5

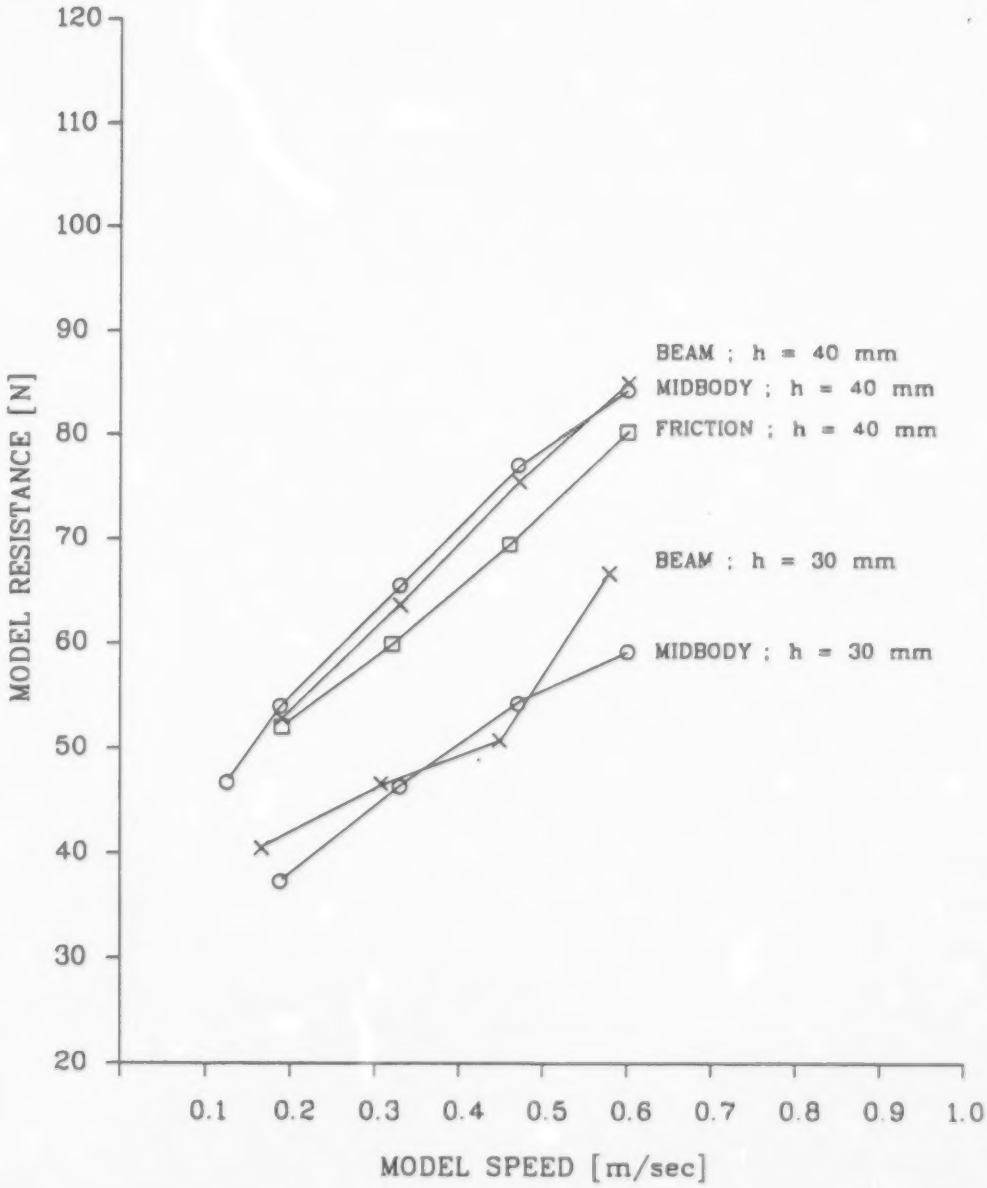
MODEL RESISTANCE vs ICE STRENGTH FOR THE BASE BEAM, BASE MIDBODY




Target Ice Thickness = 30 mm
Target Ice Strength = 25 kPa
Friction Coefficient = 0.1

FIGURE C.6

CORRECTED MODEL RESISTANCE vs SPEED FOR THE BEAM MIDBODY AND FRICTION TEST PROGRAMS

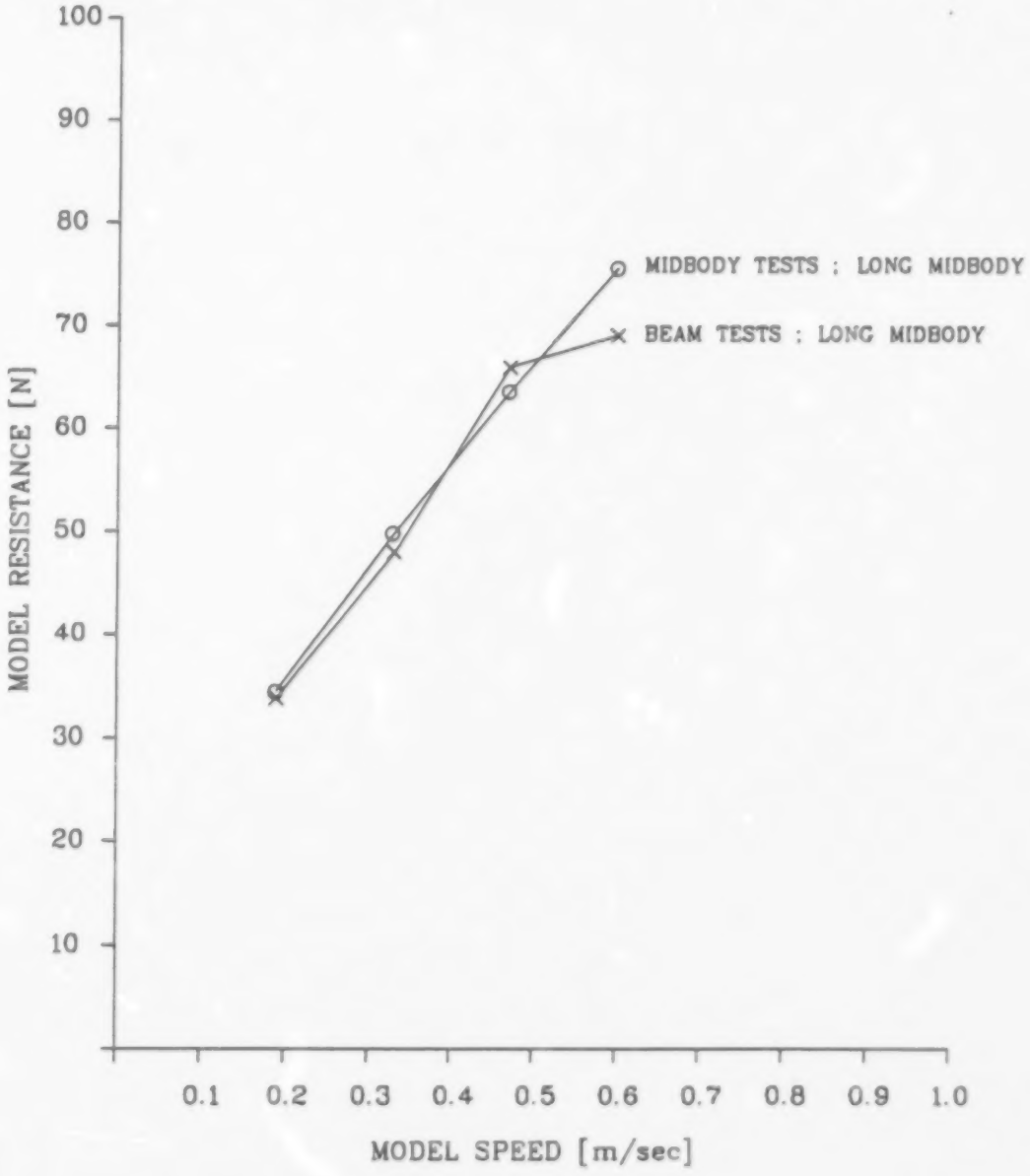



Target Ice Thickness = 30 and 40 mm
Target Ice Strength = 16.67 kPa
Target Friction Coefficient = 0.06

FIGURE C.7

MODEL TEST RESISTANCE vs SPEED FOR THE

BASE BEAM, LONG MIDBODY ; MIDBODY AND BEAM TESTS



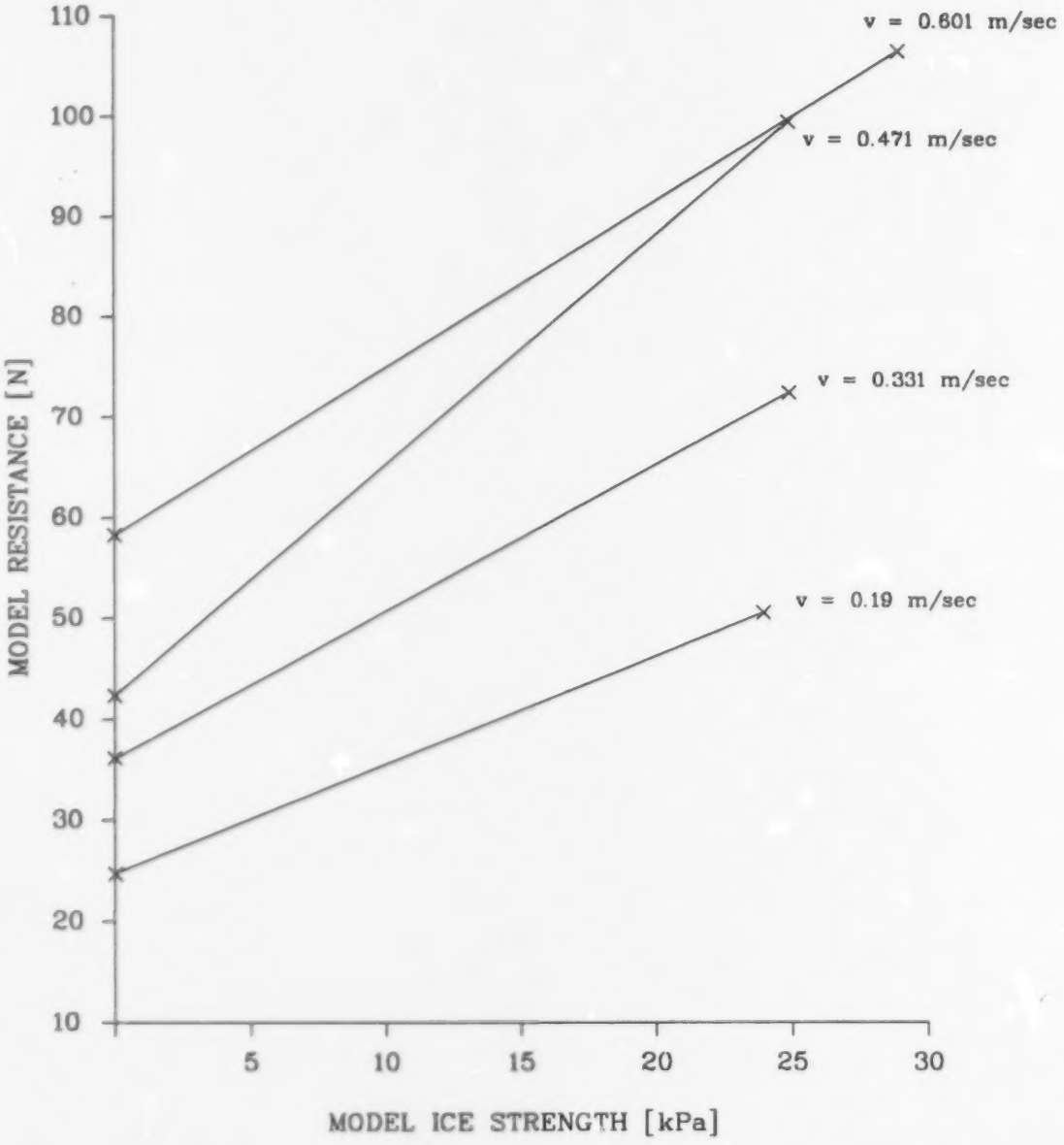

Target Ice Thickness = 30 mm

Target Ice Strength = 16.67 kPa

Target Friction Coefficient = 0.06

FIGURE C.8

MODEL RESISTANCE vs STRENGTH FOR THE BASE BEAM LONG MIDBODY

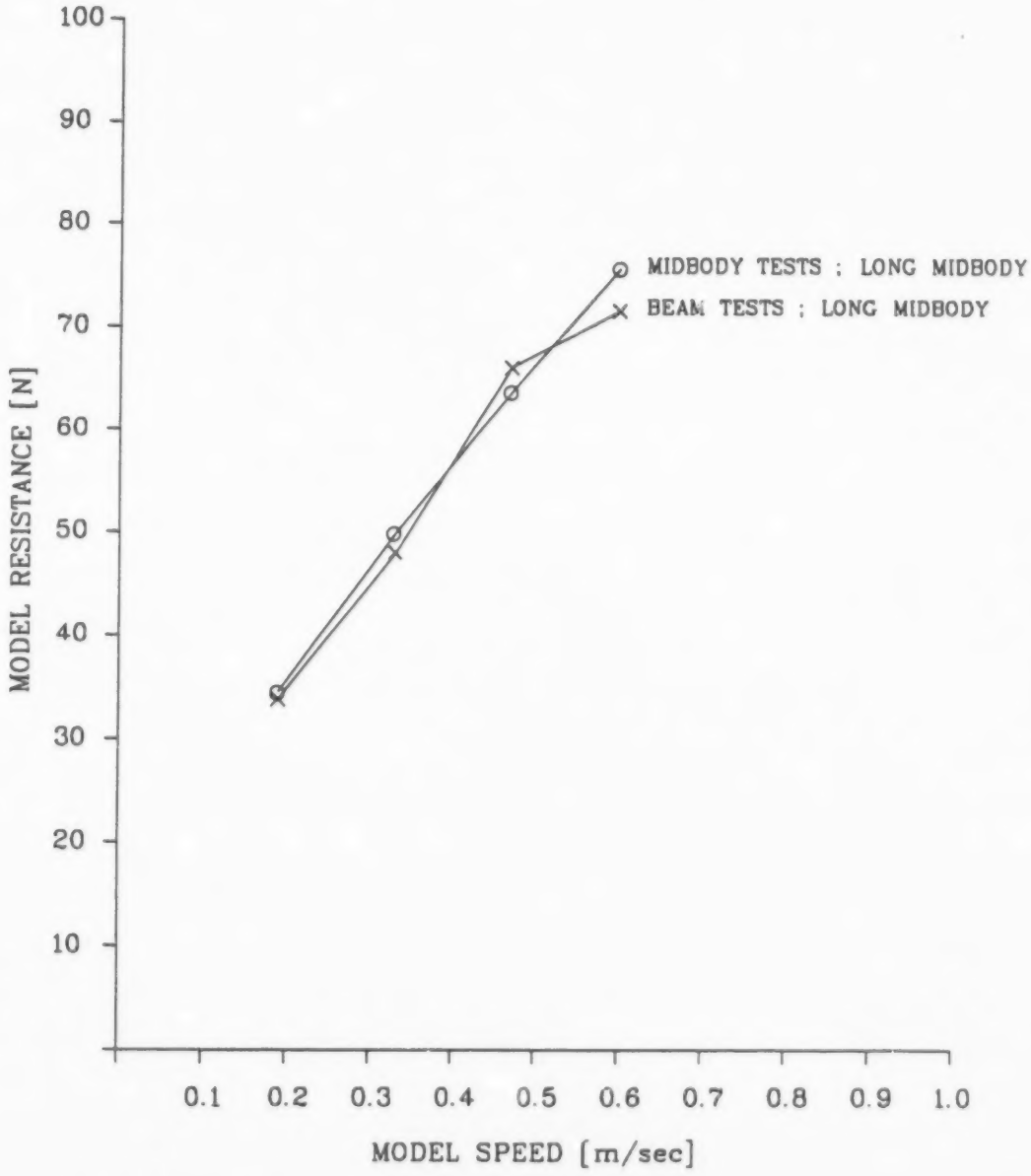



Target Ice Thickness = 30 mm
Target Ice Strength = 25 kPa
Friction Coefficient = 0.1

FIGURE C.9

MODEL TEST RESISTANCE vs SPEED FOR THE

LONG MIDBODY BASE BEAM ; MIDBODY AND BEAM TESTS



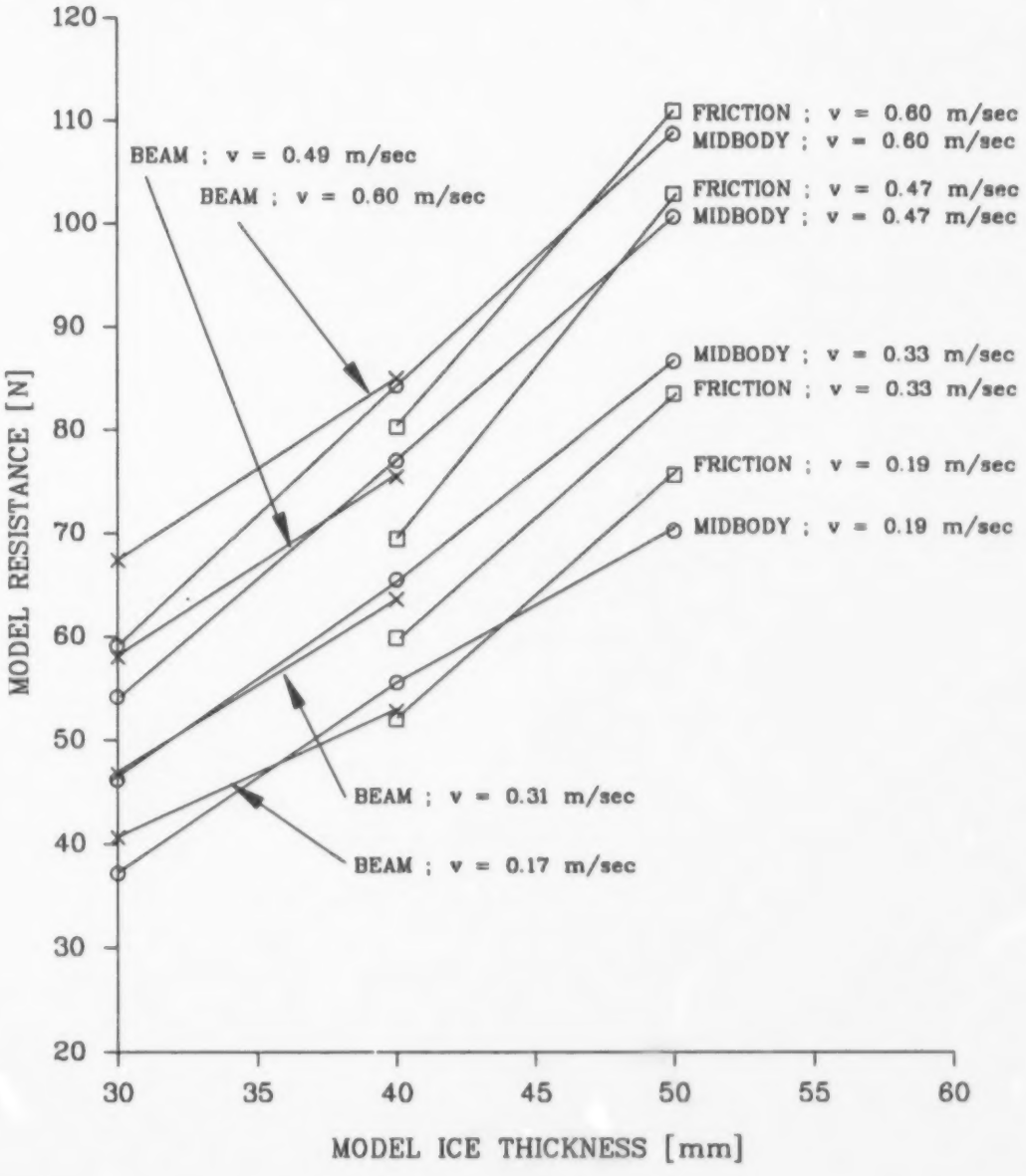

Target Ice Thickness = 30 mm

Target Ice Strength = 16.67 kPa

Target Friction Coefficient = 0.06

FIGURE C.10

MODEL RESISTANCE vs THICKNESS FROM THE FRICTION, MIDBODY AND BEAM TEST PROGRAMS




Target Ice Thickness = 30, 40 and 50 mm
Target Ice Strength = 16.67 kPa
Target Friction Coefficient = 0.06

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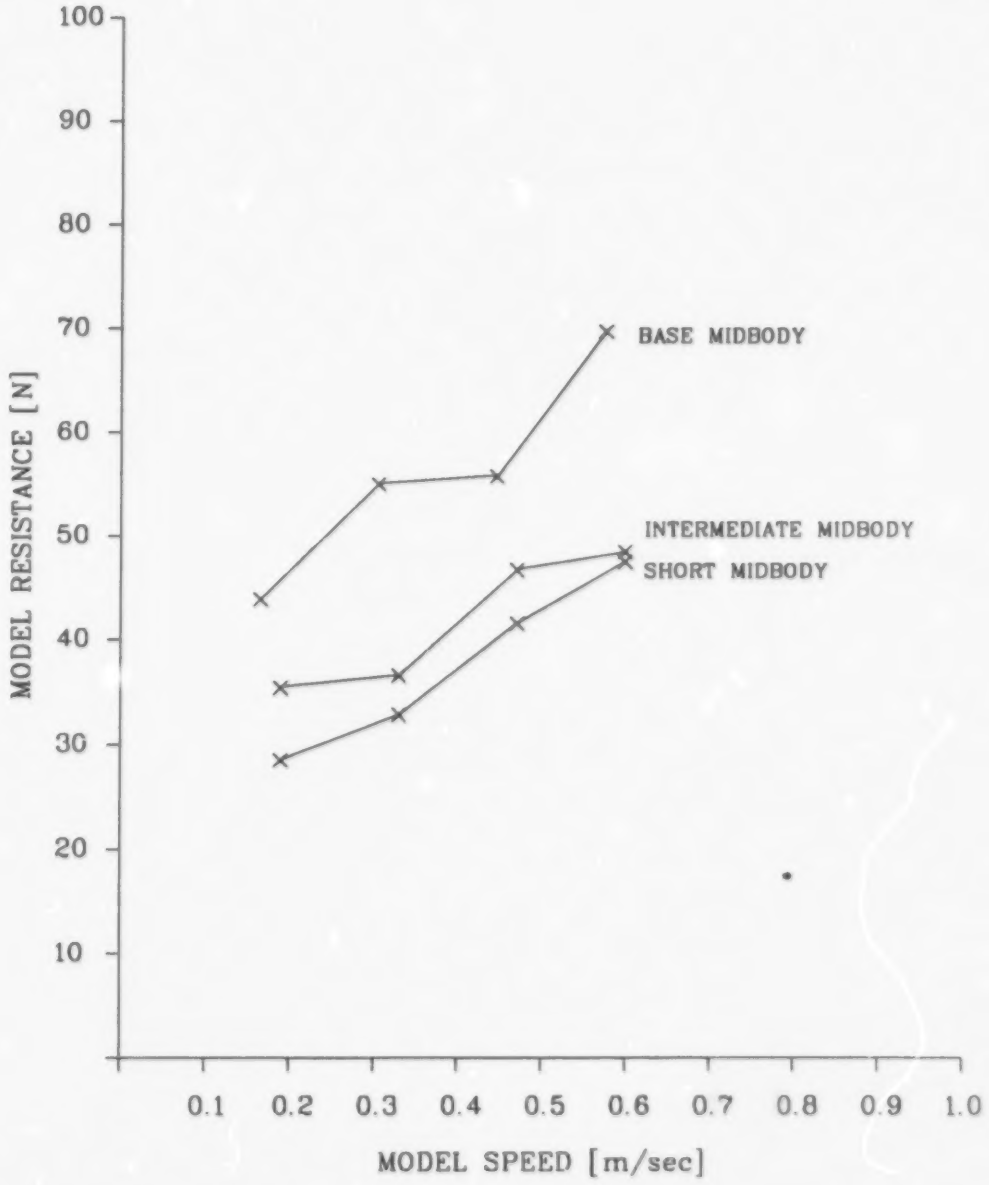
FIGURE C.11

MODEL RESISTANCE vs SPEED FOR THE

DECREASED BEAM BASE, INTERMEDIATE AND SHORT MIDBODY



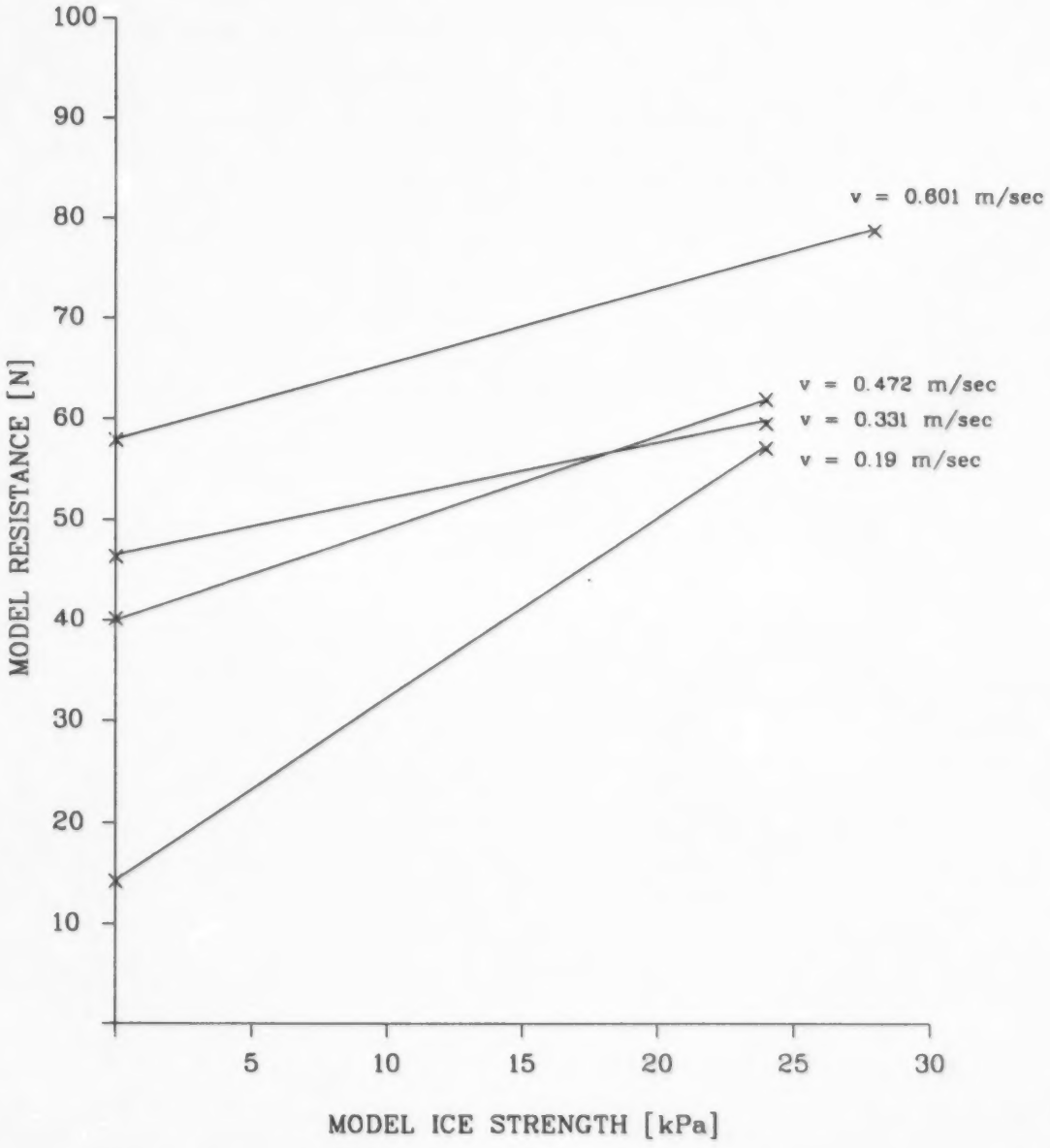

Target Ice Thickness = 30 mm

Target Ice Strength = 16.67 kPa

Target Friction Coefficient = 0.12

FIGURE C.12

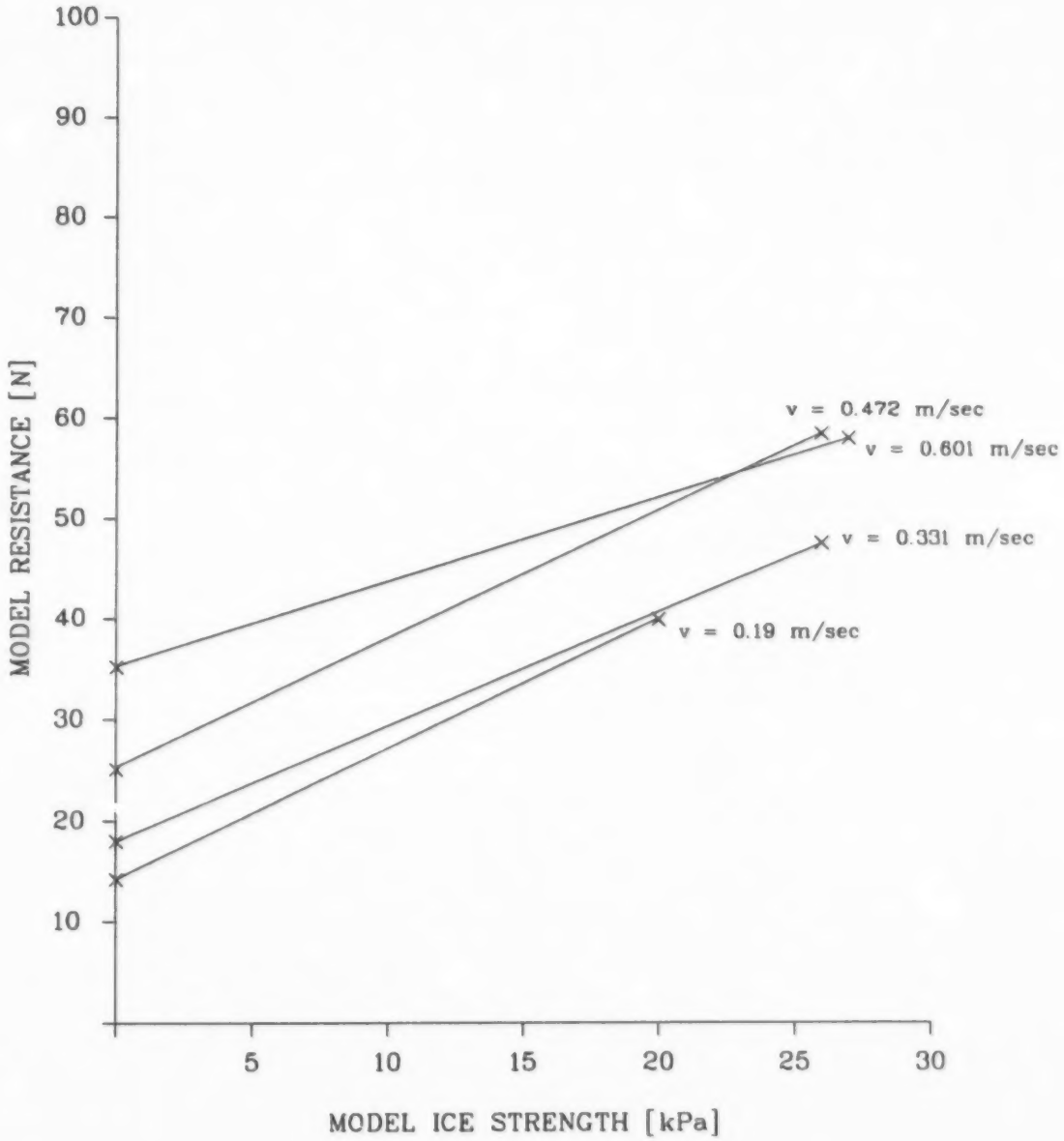
MODEL RESISTANCE vs ICE STRENGTH FOR THE DECREASED BEAM BASE LENGTH




Target Ice Thickness = 30 mm
Target Ice Strength = 25 kPa
Measured Friction Coefficient = 0.12

FIGURE C.13

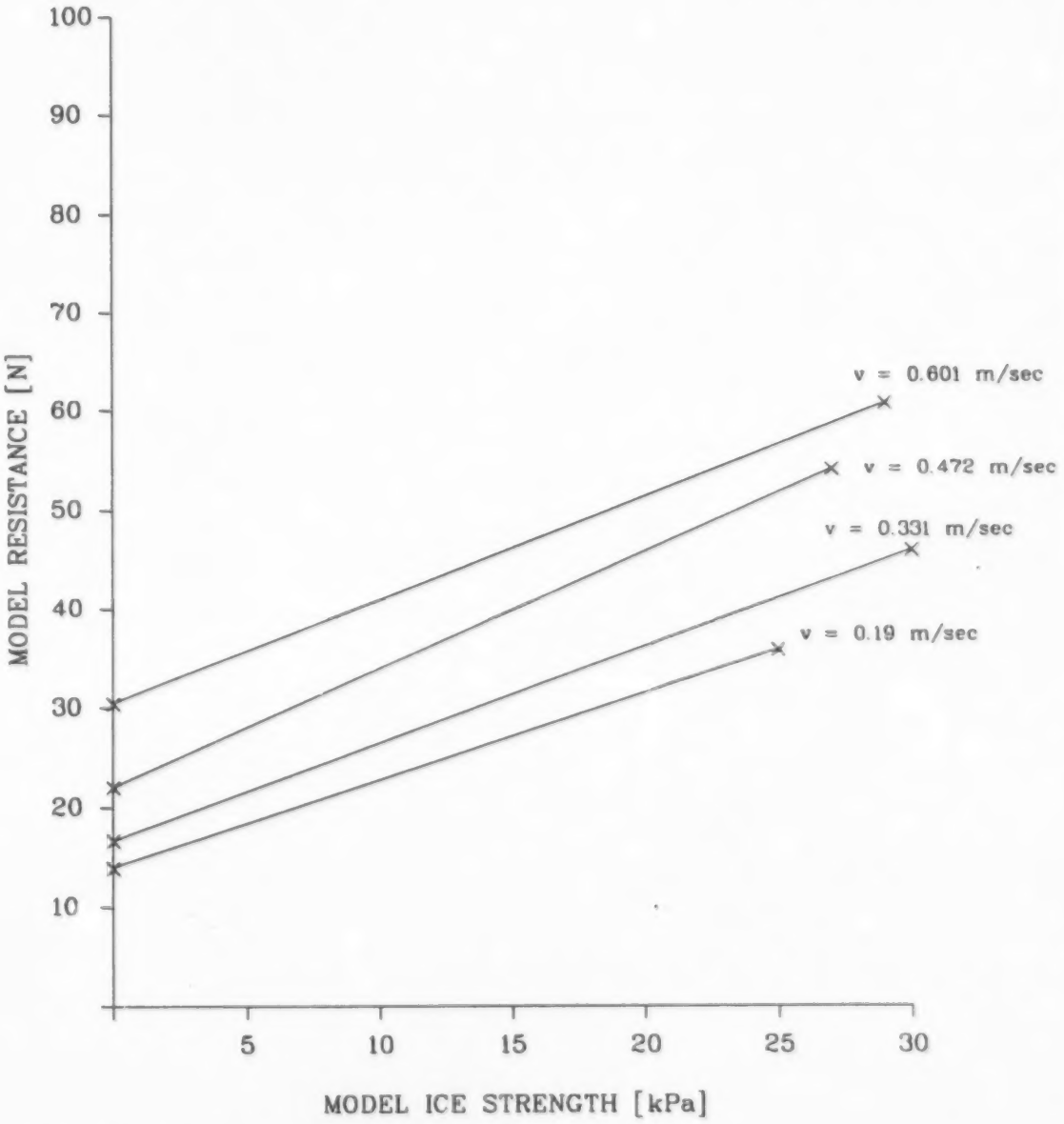
MODEL RESISTANCE vs ICE STRENGTH FOR THE DECREASED BEAM INTERMEDIATE LENGTH




Target Ice Thickness = 30 mm
Target Ice Strength = 25 kPa
Measured Friction Coefficient = 0.12

FIGURE C.14

MODEL RESISTANCE vs ICE STRENGTH FOR THE DECREASED BEAM SHORT LENGTH




Target Ice Thickness = 30 mm
Target Ice Strength = 25 kPa
Measured Friction Coefficient = 0.12

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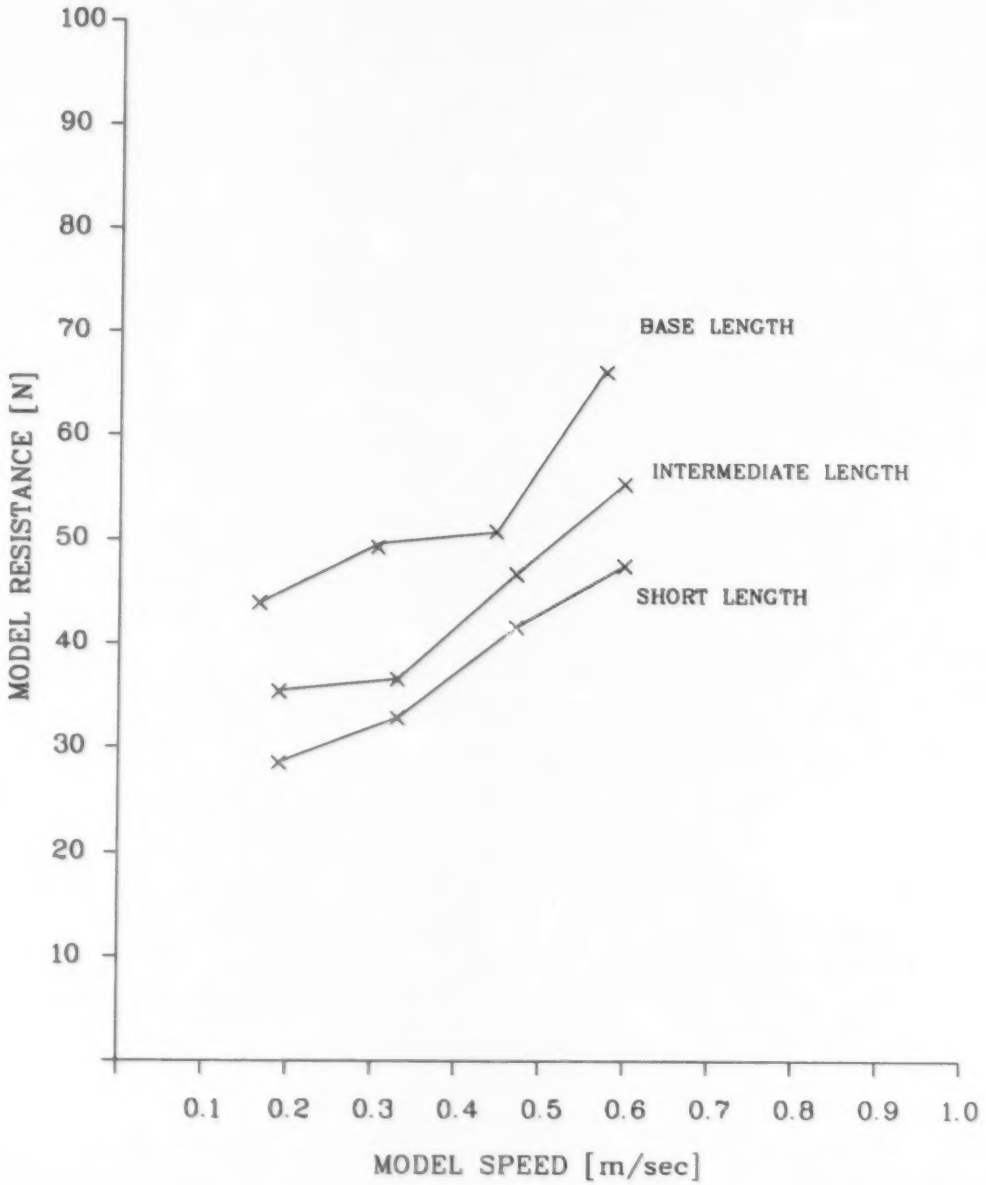
FIGURE C.15

MODEL RESISTANCE vs SPEED FOR THE

DECREASED BEAM BASE, INTERMEDIATE AND SHORT MIDBODY




Target Ice Thickness = 30 mm

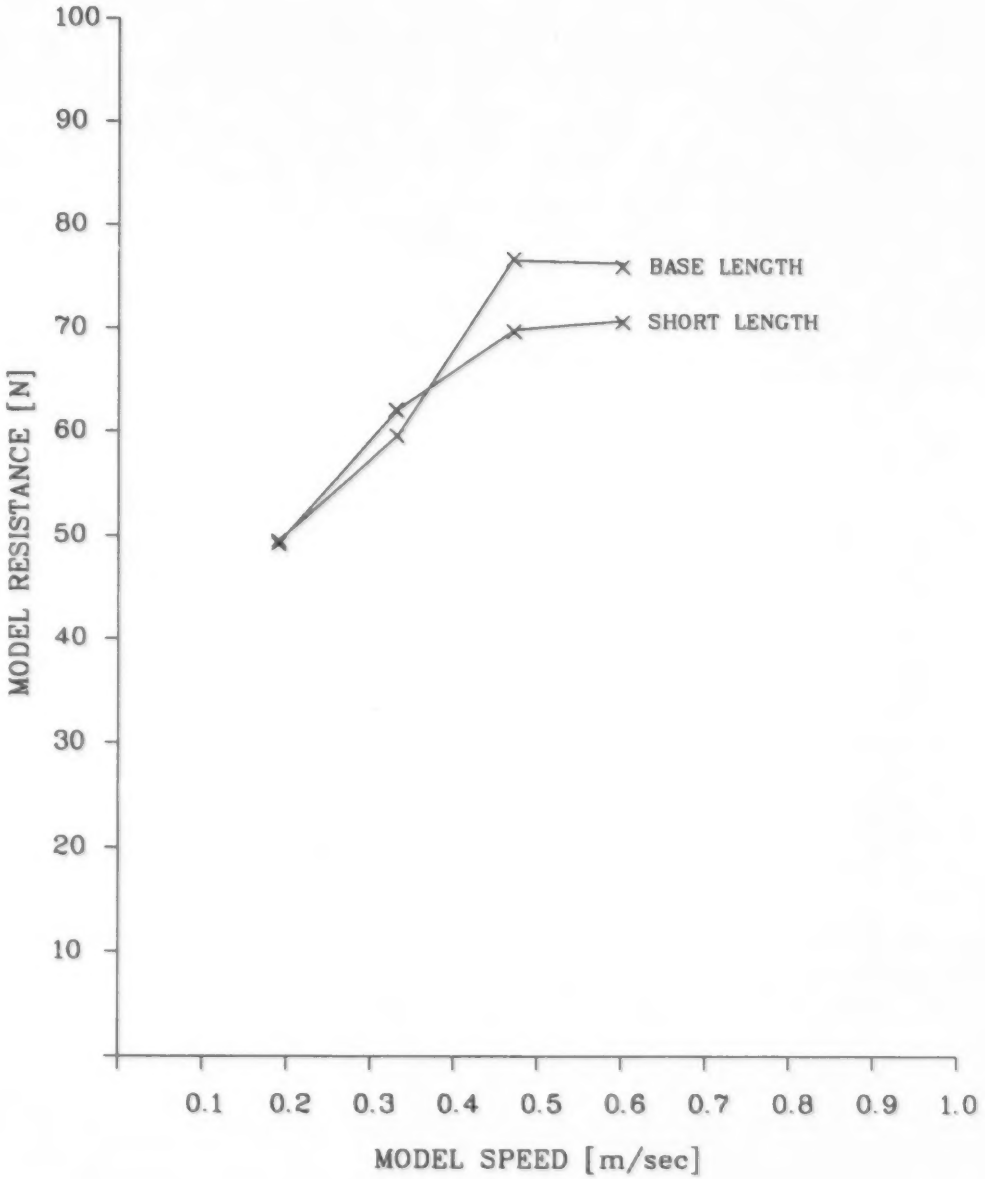
Target Ice Strength = 16.67 kPa

Friction Coefficient = 0.12

FIGURE C.16

MODEL RESISTANCE vs SPEED FOR THE

INCREASED BEAM BASE AND SHORT MIDBODIES



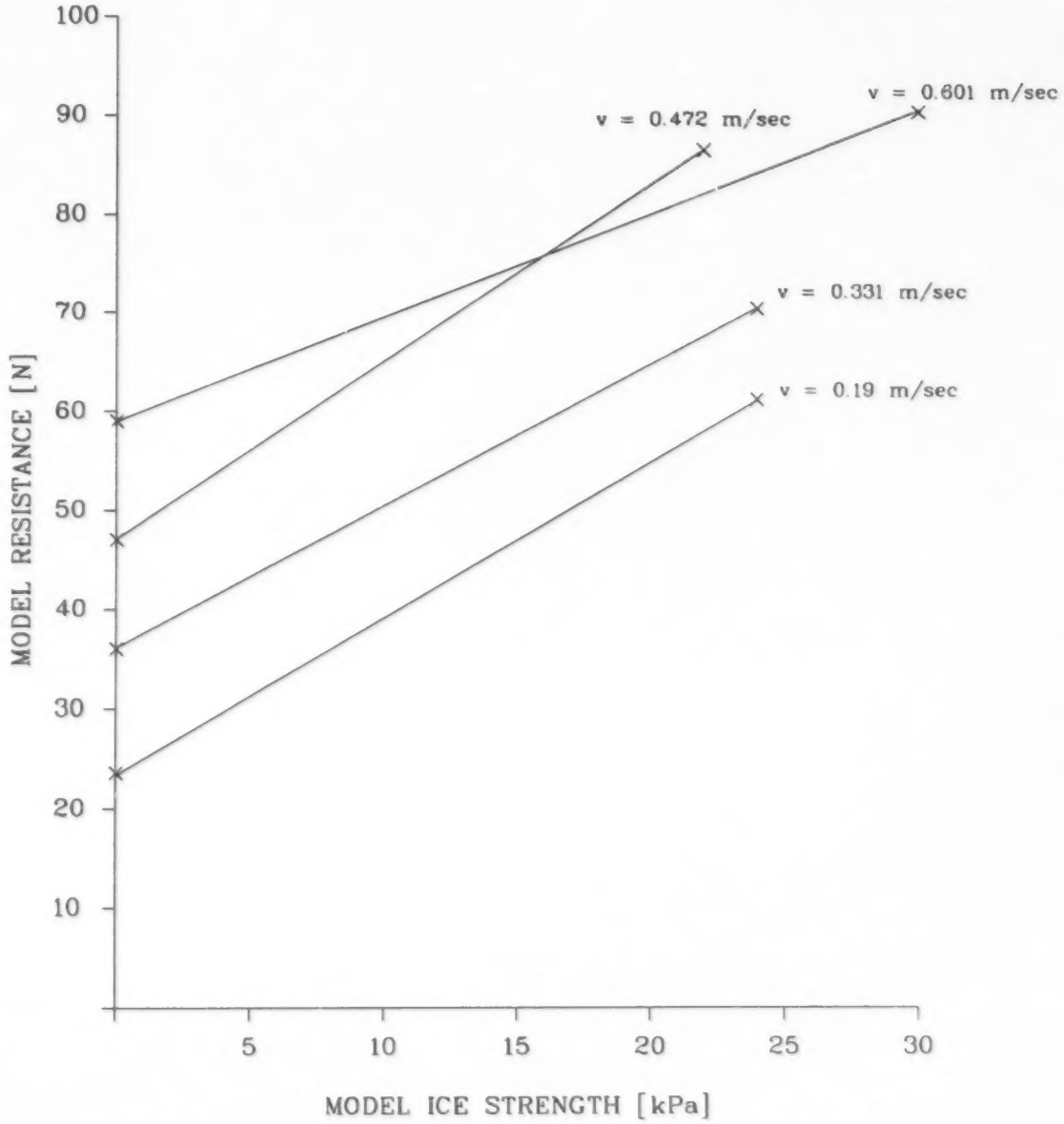

Target Ice Thickness = 30 mm

Target Ice Strength = 16.67 kPa

Friction Coefficient = 0.068

FIGURE C.17

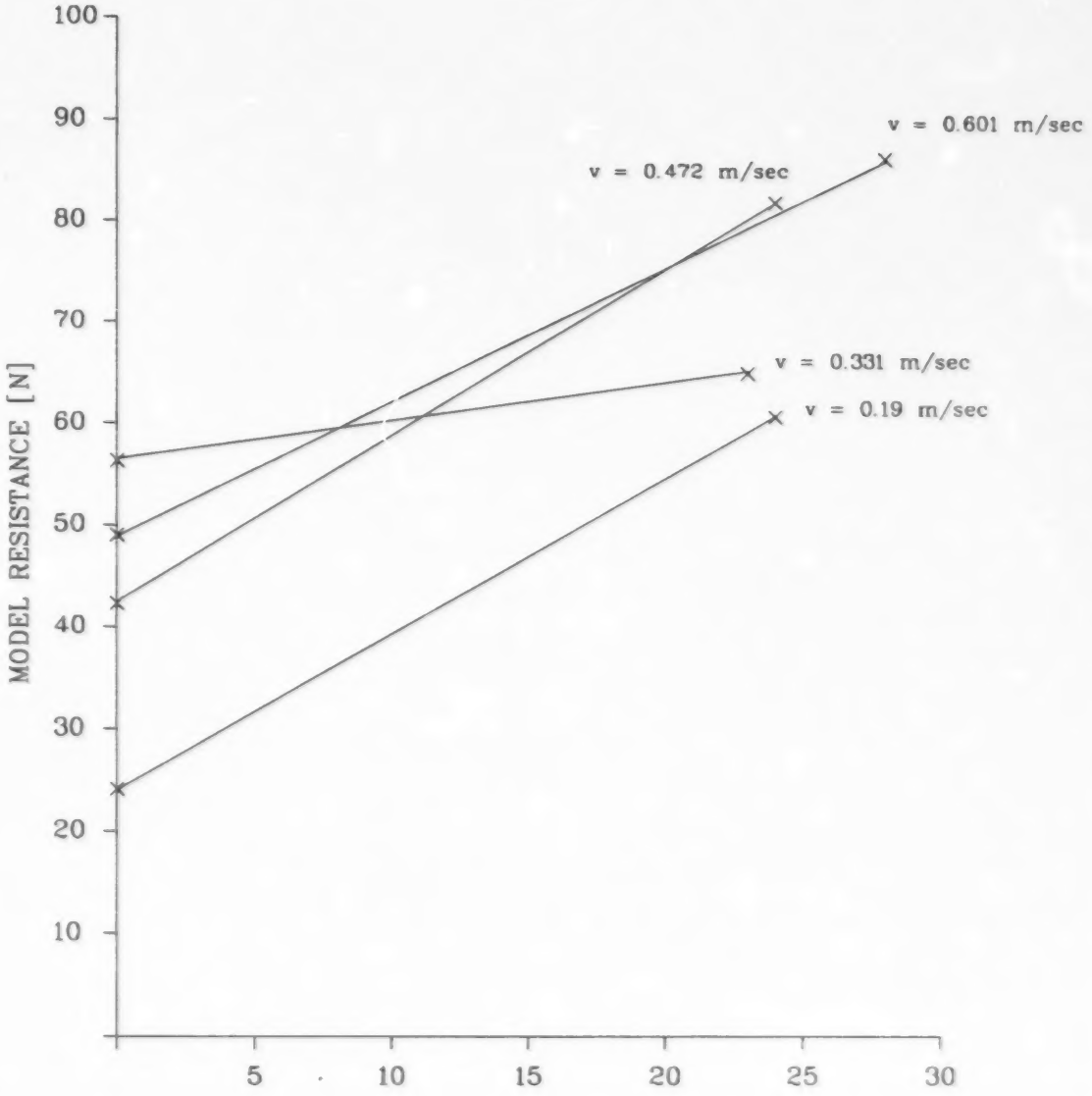
MODEL RESISTANCE vs ICE STRENGTH FOR THE INCREASED BEAM BASE LENGTH




Target Ice Thickness = 30 mm
Target Ice Strength = 25 kPa
Friction Coefficient = 0.068

FIGURE C.18

MODEL RESISTANCE vs ICE STRENGTH FOR THE INCREASED BEAM SHORT LENGTH

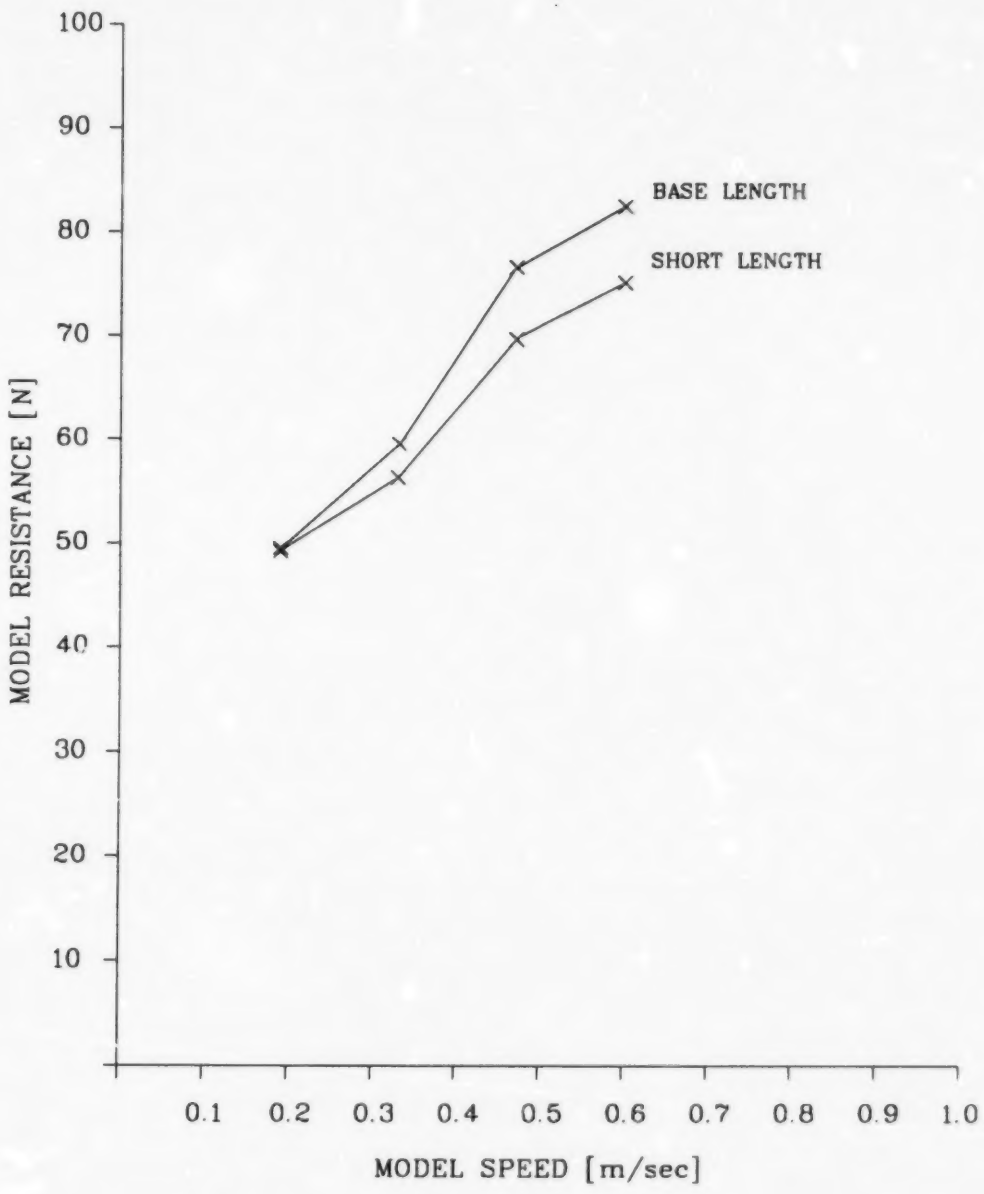



Target Ice Thickness = 30 mm
Target Ice Strength = 25 kPa
Friction Coefficient = 0.068

FIGURE C.19

MODEL RESISTANCE vs SPEED FOR THE

INCREASED BEAM BASE AND SHORT MIDBODIES




Target Ice Thickness = 30 mm

Target Ice Strength = 16.67 kPa

Friction Coefficient = 0.068

TABLE C.1
BEAM TEST RESULTS
UNCORRECTED DATA

| COLUMN # | 2 SPEED (m/s) | 3 ICE THICK (mm) | 4 FLEXURAL STRENGTH (kPa) | 5 LEVEL ICE RESISTANCE | 6 PRESAWN ICE RESISTANCE |
|---|---|---|---|---|---|
| MB01/O/O/30 | 0.166 | 29.50 | 21.00 | 59.00 | 19.00 |
| MB01/O/O/30 | 0.307 | 29.60 | 24.00 | 73.00 | 22.00 |
| MB01/O/O/30 | 0.448 | 30.00 | 16.67 | 71.56 | 32.00 |
| MB01/O/O/30 | 0.578 | 29.30 | 22.00 | 94.00 | 38.00 |
| MB05/O/O/40 | 0.190 | 39.30 | 20.00 | 68.00 | 35.00 |
| MB05/O/O/40 | 0.330 | 39.80 | 22.00 | 93.00 | 41.00 |
| MB05/O/O/40 | 0.471 | 39.20 | 17.00 | 101.00 | 49.00 |
| MB05/O/O/40 | 0.601 | 40.00 | 16.67 | 105.00 | 59.00 |
| MB02/D/O/30 | 0.166 | 29.50 | 24.00 | 56.60 | 13.50 |
| MB02/D/O/30 | 0.307 | 29.70 | 24.00 | 61.40 | 38.70 |
| MB02/D/O/30 | 0.448 | 29.60 | 24.00 | 58.56 | 46.30 |
| MB02/D/O/30 | 0.578 | 29.10 | 28.00 | 77.80 | 55.60 |
| MB03/D/I/30 | 0.190 | 28.90 | 20.00 | 39.20 | 12.00 |
| MB03/D/I/30 | 0.331 | 29.20 | 26.00 | 46.50 | 16.00 |
| MB03/D/I/30 | 0.472 | 29.20 | 26.00 | 56.60 | 24.00 |
| MB03/D/I/30 | 0.601 | 30.00 | 27.00 | 56.80 | 32.00 |
| MB04/D/S/30 | 0.190 | 29.90 | 25.00 | 35.70 | 13.90 |
| MB04/D/S/30 | 0.331 | 29.70 | 30.00 | 45.50 | 16.10 |
| MB04/D/S/30 | 0.472 | 30.50 | 27.00 | 55.10 | 22.50 |
| MB04/D/S/30 | 0.601 | 29.80 | 29.00 | 60.50 | 29.50 |
| MB06/O/L/30 | 0.190 | 29.10 | 24.00 | 50.00 | 23.00 |
| MB06/O/L/30 | 0.331 | 29.30 | 25.00 | 71.00 | 33.00 |
| MB06/O/L/30 | 0.472 | 28.80 | 25.00 | 90.16 | 40.00 |
| MB06/O/L/30 | 0.601 | 28.20 | 29.00 | 104.00 | 52.00 |
| MB07/I/O/30 | 0.190 | 29.90 | 24.00 | 61.00 | 23.00 |
| MB07/I/O/30 | 0.331 | 30.40 | 24.00 | 71.00 | 36.00 |
| MB07/I/O/30 | 0.472 | 30.20 | 22.00 | 87.00 | 47.00 |
| MB07/I/O/30 | 0.601 | 29.90 | 30.00 | 90.00 | 58.00 |
| MB08/I/S/30 | 0.190 | 30.00 | 24.00 | 60.50 | 23.50 |
| MB08/I/S/30 | 0.331 | 30.20 | 23.00 | 65.10 | 35.30 |
| MB08/I/S/30 | 0.472 | 30.00 | 24.00 | 81.60 | 42.50 |
| MB08/I/S/30 | 0.601 | 29.70 | 28.00 | 85.60 | 47.60 |